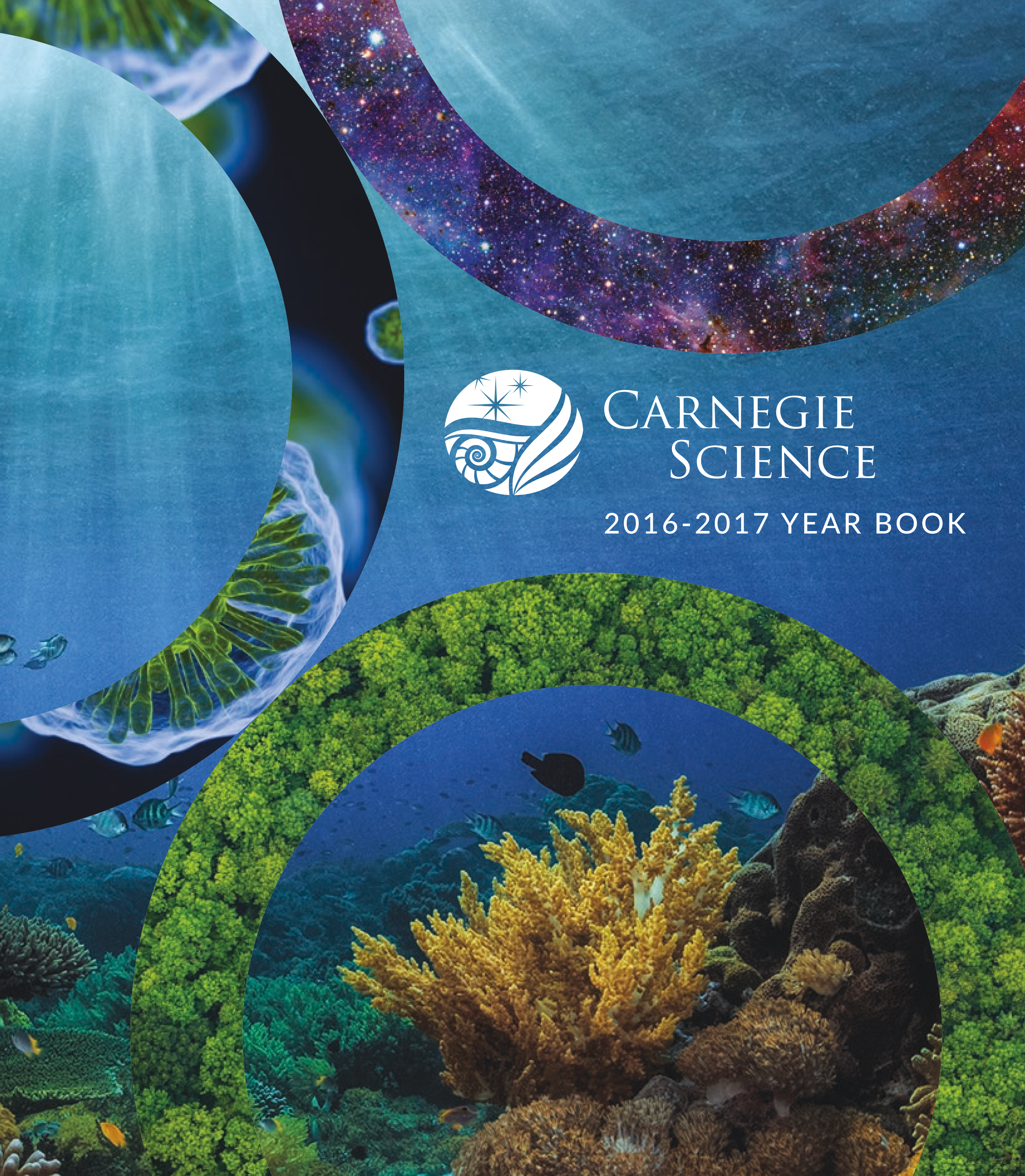

Carnegie Science

2016-2017 Year Book

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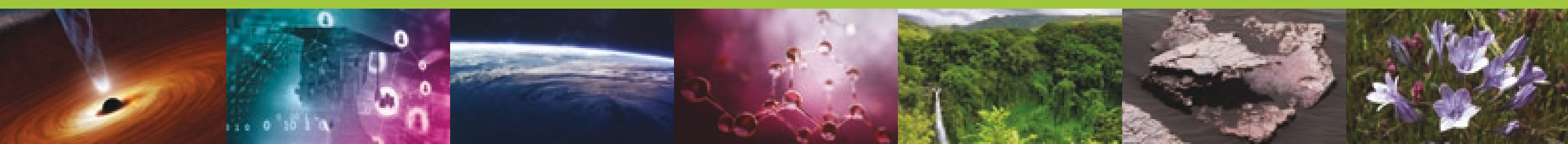

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2016-2017 YEAR BOOK

The President's Report

July 1, 2016 - June 30, 2017

CARNEGIE INSTITUTION FOR SCIENCE

Former Presidents

Former Trustees

About Carnegie

“. . . to encourage, in the broadest and most liberal manner, investigation, research, and discovery, and the application of knowledge to the improvement of mankind . . .”

The Carnegie Institution was incorporated with these words in 1902 by its founder, Andrew Carnegie. Since then, the institution has remained true to its mission. At six research departments across the country, the scientific staff and a constantly changing roster of students, postdoctoral fellows, and visiting investigators tackle fundamental questions on the frontiers of biology, earth sciences, and astronomy.

Carnegie Institution for Science

Contents

Carnegie's Impact on Discovery

“The trend that has begun and will, I think, continue is of greater integration of Space, Earth, and Life.”

As most of you know, I decided to retire from Carnegie at the end of 2017. My three-year tenure was one of the most satisfying periods of my career. I am honored to have been able to help guide such a wonderful institution towards the future. Carnegie is filled with remarkable scientists, technical and engineering staff, and administrators whom I have been lucky to have as colleagues and as friends. I have thoroughly enjoyed my time here. It has been exciting to learn from such extraordinary scientists—people at different stages of their careers, with immensely diverse and fascinating interests, people whose discoveries are reshaping our understanding of the workings and history of the universe, our planet, and life.

Andrew Carnegie’s original conception of the institution as a haven for extraordinary people is reflected in our institution today. The freedom and security we provide to scientists is what underlies our past and present successes, and is what we must most carefully protect in the future. This goal is simply stated, but is difficult in practice. During my tenure, we embarked on improving methods and ideas and insights of science by leading new enterprises, yet maintaining enough stability to give time for exploration, side tracks, dead ends, and surprises that always accompany progress.

As an institution that cherishes individual explorers, we consider how to balance science done by individuals and small teams with the opportunities that grow from engagement with global scientist networks. We have scientists who work largely alone, and others who, for example, created the Deep Carbon Observatory that links hundreds of scientists in dozens of countries. And we partner with other institutions, as in the Giant Magellan Telescope Organization.

No one style defines Carnegie and, as science goes forward, we must adapt while leading. We cheer as our researchers come up with fresh and sometimes irreverent thoughts, chase exciting ideas, and nimbly pioneer new fields. Our core values of independence and flexibility are essential.

Living among our scientists changes scales of reference. Some describe the recently detected collision of two neutron stars as “nearby,” when they are 130 million light years away. “Young” erratic rocks shown to me by Terrestrial Magnetism scientists in the Canadian arctic were tens of millions of years old. Our biologists routinely talk about how essentially the same gene operates in different animals, their common ancestor having lived hundreds of millions of years before. It’s incredibly fun to share perspectives of deep time and unfamiliar worlds. Many people reading these words have had such experiences at Carnegie events.

The future of Carnegie Science will involve greater integration among our fields of work, taking advantage of our breadth to strengthen our depth, and to use novel approaches. For those who believe in the power of small private institutions to transform the world, and for those who value science as a way to see both the past and future in new light, the proven style and vast accomplishments of Carnegie Science promise an extraordinary future. I look forward to following and celebrating Carnegie’s exciting and ever-evolving scientific pursuits, and we can begin right here.

Image courtesy Matthew Scott

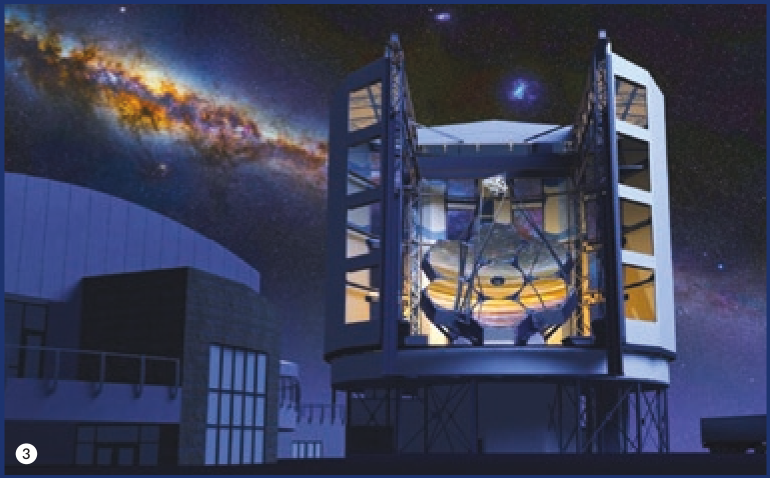


Image courtesy Giant Magellan Telescope Organization

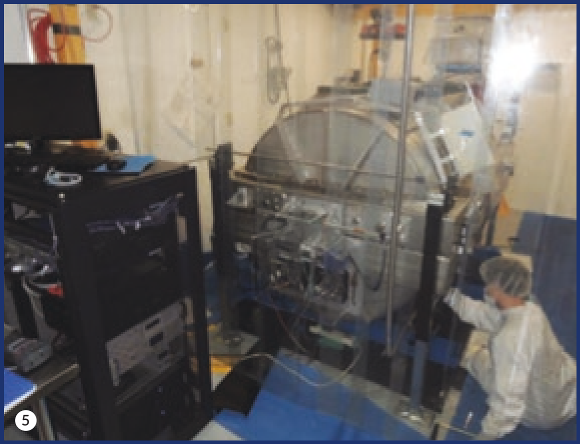


Image courtesy Carnegie Observatories

Space

Among our astronomers are theorists, observers, and instrument developers. That interdisciplinary intellectual environment is well-suited to generating surprises. Theorists are drawn into observing, observers devise new goals based on theory, instrument developers devise ways to test theories and explore observations. A cycle of observation-theory-invention-observation . . .

We have as an ideal that our researchers create new tools—tools for seeing what has not been seen before. Carnegie researchers have a long history of developing large telescopes and sophisticated astronomical instrumentation. It began in 1904 when George Ellery Hale obtained support from the newly formed Carnegie Institution to found the Mount Wilson Solar Observatory in the mountains near Pasadena, CA. He led the conception and construction of the largest telescopes in the world—first the 60-inch telescope, then the 100-inch Hooker telescope, which reached its hundredth birthday this year, and then the 200-inch telescope at Palomar Observatory. This tradition continues today at Carnegie's Las Campanas Observatory in Chile, home to the Swope 1-meter, the du Pont 2.5-meter, and the twin Magellan 6.5-meter telescopes (1). The Swope, our smallest and oldest telescope there, was the first telescope in the world to see the optical signal emanating from a neutron star-neutron star collision just this past August. Our telescopes have discovery lifetimes of many decades, especially since renovations and new instruments keep them vibrant.

Las Campanas hosts another collaborative telescope project, the Giant Magellan Telescope (GMT). Construction of GMT has begun on our Las Campanas peak, not far from the Magellans (2). The 24.5-meter GMT (3, artist's concept) will be among the giant ground-based telescopes that promise to revolutionize our understanding of the universe. Eight 8.4-meter mirrors are being made at the University of Arizona's Richard F. Caris Mirror Laboratory (4); seven at a time will be arranged in a floral pattern in the telescope to effectively form one giant mirror. Initial commissioning is scheduled for 2023.

To advance astronomy, telescopes need to push the limits of instrumentation. Carnegie astronomers have the unusual distinction of excelling in the design and implementation of cutting-edge instruments. APOGEE-S is the first new instrument for the du Pont telescope in over 20 years (5). It will take spectra of hundreds of stars in one exposure. The data, combined with data from a sister spectrograph in the north, will provide a map of the entire Milky Way in unprecedented detail. The image at right (6) is from the first set of observations. The blue dots are targeted stars. A sample of the spectra, indicating chemical composition is shown at top (6).

Image courtesy Las Campanas Observatory

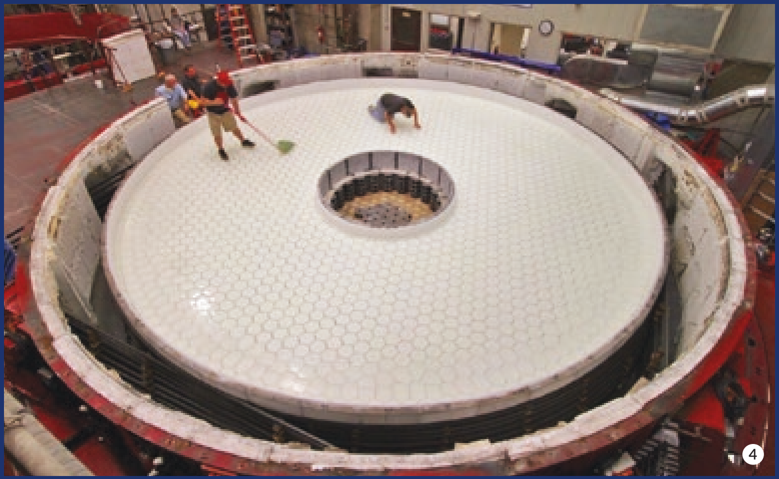


Image courtesy University of Arizona

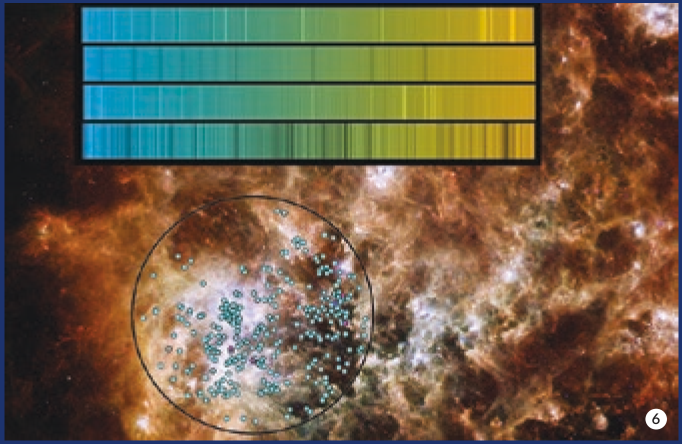


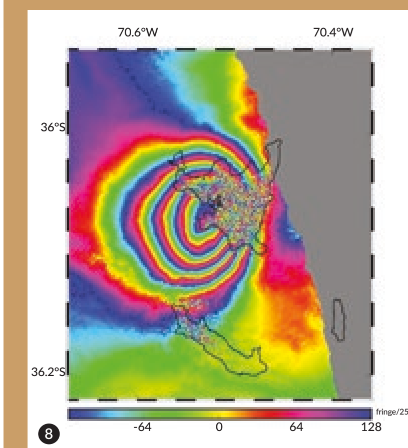
Image courtesy Carnegie Observatories

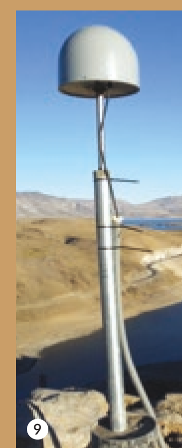
Earth

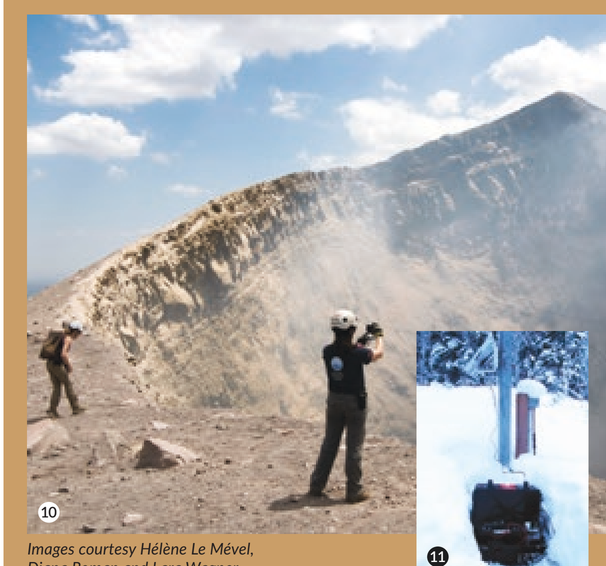
One of our newest staff scientists, Hélène Le Mével (7), has joined our team that explores the causes of volcanic eruptions, with the goals of understanding how volcanoes work and determining how eruptions can be predicted. The group uses precise GPS and gravity measurements to detect bulging around a volcano in Chile (8). They measure how the ground deforms, using Interferometric Synthetic Aperture Radar (InSAR) (9). Our staff scientists Lara Wagner and Diana Roman (10) have designed and built a quick-deploy seismometer system that is being tested in Alaska (11). The plan is to quickly move instrumentation to new eruption sites.

Carnegie's exceptional strengths in the science of extreme pressures and temperatures are applied to planetary science and to creating novel materials. Yingwei Fei (12, left), a high-pressure experimentalist, and Peter Driscoll (12, right), a theoretical geophysicist, have joined forces in a novel approach for investigating properties and dynamics of super-Earths—extrasolar planets with masses between one and ten times that of Earth. They will use the world's most powerful magnetic pulsed-power radiation source, the Z Machine at Sandia National Laboratory (13), to generate shock waves that simulate intense pressure conditions typical of these enormous bodies. Reaching such high pressures has not been possible before. The results will help develop models and predictions about super-Earth interiors. The Department of Energy recently allowed a few institutions to use the Z Machine. Fei's team was granted access after a highly competitive application process.

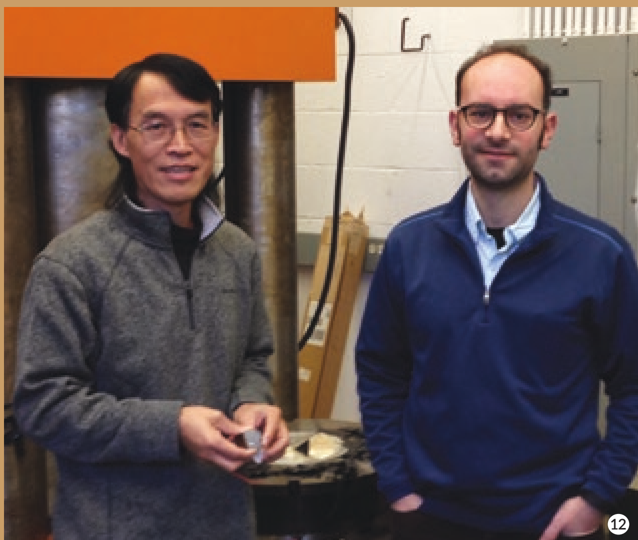
Material scientists work in labs at Carnegie in Washington, DC, (14) and use Carnegie-managed facilities like sector 16 of the Advanced Photon Source (APS) in Argonne, IL. APS (15) allows scientists to study material properties at the smallest scales using high-energy X-rays. High-pressure and temperature conditions found deep in the interior of planets squeeze atoms and electrons so close together that electrons behave bizarrely and new types of matter can form. Material scientists, such as Tim Strobel and his team (14), harness these conditions to create new materials with myriad potential applications, including ultra-strong, hard and elastic compressed glassy carbon (14, lower left). Its unique properties could serve applications from aerospace engineering to military armor. The Strobel lab also created a new form of silicon (14, lower right), which could be used for electrical energy storage or molecular-scale filtering.

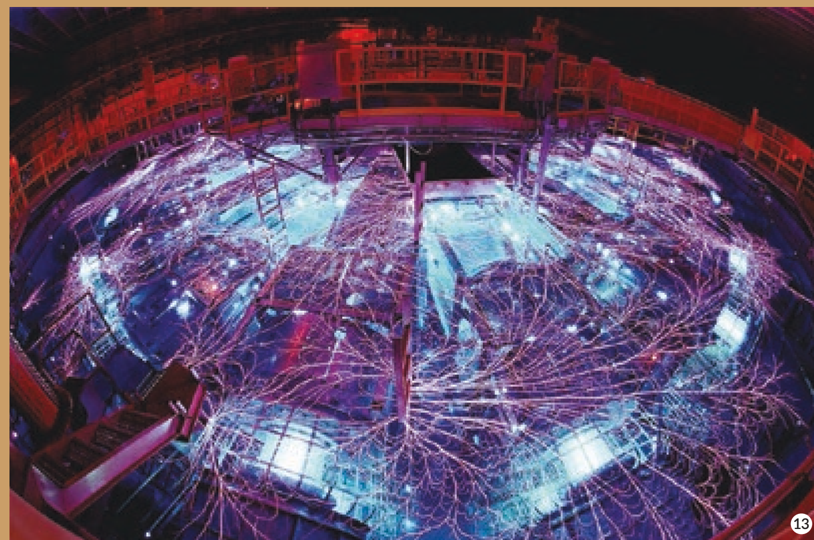




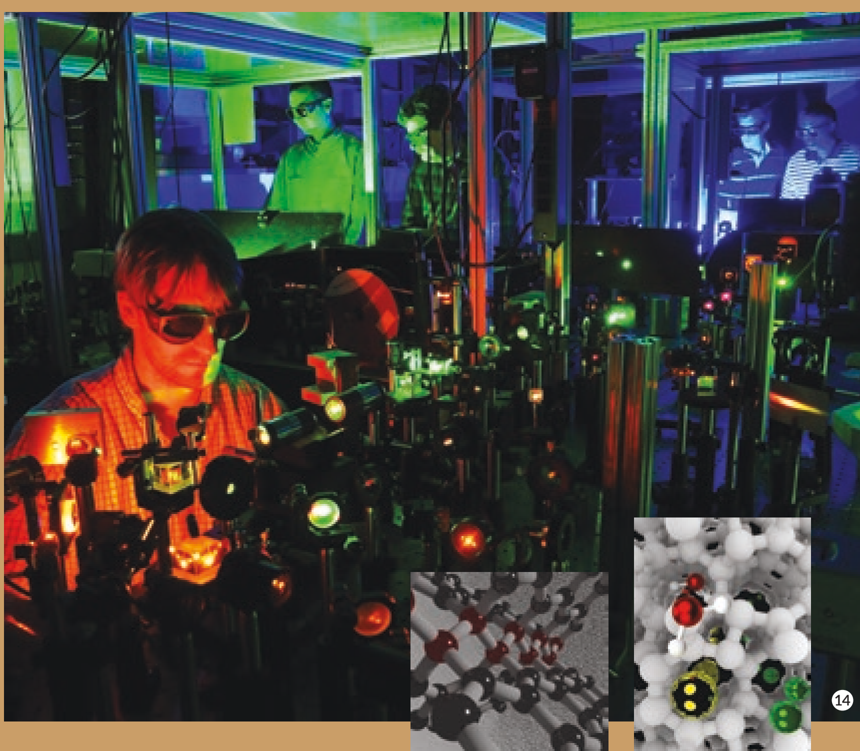


Images courtesy Hélène Le Mével, Diana Roman and Lara Wagner





Images courtesy Yingwei Fei, Peter Driscoll, and Sandia Labs



Images courtesy Tim Strobel and Argonne National Laboratory

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Images courtesy Robin Kempster and Department of Embryology

Life

Carnegie's life scientists study microbial, plant and animal science, and global ecology, from genes to ecosystems, and even to the possibility of life on other Earths. Since 1953, when the structure of DNA was reported, life scientists have been trying to understand how structures and behaviors of organisms are encoded in genes. Much remains to be learned about how inheritance works, how tens of thousands of genes build functional forms, roots and flowers, muscles and brains, movement and memory. Organisms do not live in isolation; some depend on social groups, and all live in ecosystems where microbes interact with plants and animals and diversification is driven by competition. Evolution is the combination of genetic change with selective survival. The incredible and beautiful diversity of life is the outcome of variations in genes and form. Increasingly Carnegie will take advantage of its strengths in biology and Earth science to bring these fields closer.

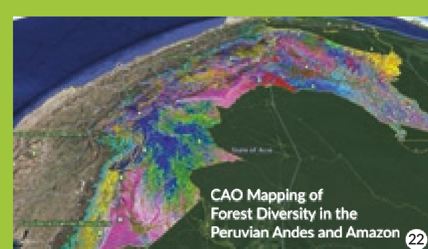
Understanding genes and processes that underlie the development of plants and animals addresses the great mysteries of inheritance and evolution, while also providing new ideas for agriculture and medicine. Carnegie plant scientists work at understanding photosynthesis and other aspects of plant physiology (16), which could produce crops that are better adapted to climate change. Spectacular work by Carnegie scientists on stem cells—cells that turn into various types of tissue like muscle or eggs—show how different tissues and organs are formed. The studies at the Department of Embryology (17) reveal paths to improving healing after injury.

Carnegie ecologists work at a different scale of biology, a scale that is really a kind of Earth science. That is why our department is called Global Ecology. Local ecosystems are important to

explore, to understand how dozens to thousands of organisms form an interdependent web of life. Local ecosystems can be viewed at a larger scale to understand how they affect, and are affected by, global events. An algal bloom such as the ones studied by Carnegie's Anna Michalak can be examined locally to understand its origins or, as she does, looked at for its impact on huge bodies of water like the Great Lakes (18).

The Great Barrier Reef of Australia can be viewed from space. Scientists in four of our departments have become fascinated by the biology and ecology of coral. At the cellular level, coral is a mutually beneficial relationship between a photosynthetic plant and an animal that catches prey by stinging. The molecular and cellular biology of this relationship, and what happens in bleaching when the plant cells depart, is a fascinating focus of some of Carnegie's laboratory research. At a global scale, millions of people depend on coral reefs for their food, but the warming and acidification of the oceans is killing reefs at a staggering rate. Our global ecologists are bringing to bear new approaches and technologies in this realm.

For example, Ken Caldeira's lab manipulates ocean acidification in the field to understand its influence (19, 20). While continuing their pioneering work on forests, Greg Asner's team uses the fixed-wing Carnegie Airborne Observatory (21), a flying lab to capture data on the chemistry and structure of the Earth below, to coral ecology. Spectral data from the CAO's special cameras have been used to construct 3-D maps that reveal forest diversity and changing features of forests (22). Now an analogous approach is used to image coral reefs through clear water, as deep as 30 meters, giving unprecedented details of variation and ecosystem patterns over vast expanses of a reef.



Images courtesy Landsat, Ken Caldeira, Greg Asner, and the Carnegie Airborne Observatory

Image courtesy Yuri Beletsky

The Remarkable Caliber and Breadth of Carnegie Science

This science sampler gives a sense of the caliber and breadth of research that our scientists are undertaking. The trend that has begun and will, I think, continue is of greater integration of Space, Earth, and Life. In the days of Hale few people other than science fiction writers were expecting life "out there." Now it seems likely that life exists somewhere among the thousands of "nearby" exoplanets being explored by our astronomers. The idea that geology happens and life merely responds is no longer tenable. Most of the Earth's minerals, as Carnegie's Robert Hazen has documented, formed in an oxygen-rich atmosphere that was created, at least in part, by oxygen-producing microbes. Now we know that life forms have a huge impact on geological processes. Our heritage provides critical ideas about how planets form and change, and why our planet is a place of life. That really is the most important feeling I take away from Carnegie Science. It is unique among science institutions, something to be celebrated, treasured, and nourished. I can't wait to see the next chapters of discoveries.

President, Carnegie Science

2016-2017 YEAR BOOK

Research Highlights

Image courtesy Zhiyong Wang Lab

Astronomy

Investigating the Birth, Structure, and Fate of the Universe

Massive Black Holes May Quash Star Birth

Astronomers have found new evidence that the growth of massive black holes in distant galaxies may be preventing the birth of new stars. A team led by Carnegie astronomer Gwen Rudie devised a method to study the gas surrounding massive galaxies in the distant universe, some 10 billion years ago. The study focused on galaxies that were forming stars at a low rate. While common today, such galaxies were extremely rare during this early epoch when most of the universe was more actively forming stars. By studying the surrounding gas, Rudie and collaborators hoped to learn why these rare galaxies were forming stars so slowly.

"Rudie uses quasars to detect intergalactic gas clouds...by searching for the shadows they cast."

The group, including Carnegie astronomer Andrew Newman, used the FourStar camera on the 6.5-meter Magellan Baade telescope to search for the chance alignment of these rare distant galaxies with even more distant quasars. Quasars are massive black holes surrounded by very hot disks of gas that shine so brightly they can be used as cosmic flashlights. Rudie uses quasars to detect intergalactic gas clouds between the quasar and Earth by searching for the shadows they cast.

Gwen Rudie and Andrew Newman conducted this work at the Magellan Baade telescope at Carnegie's Las Campanas Observatory in Chile.
Image courtesy Gwen Rudie

Some 130,000 light years away from one remarkable galaxy, they found a dense cloud of gas that contained molecules of hydrogen and carbon monoxide. Stars form from molecular gas, and it is thought that molecules only form within galaxies, so

This artist's rendition shows a quasar (far right object), which is a massive black hole surrounded by a disk of gas that is so hot it outshines all the stars in its galaxy. Quasars are so bright they can be used as cosmic flashlights to detect intergalactic gas, between Earth and them, by the shadows they imprint on the light from the quasar. Gwen Rudie and team devised a technique to detect and study the gas surrounding early massive galaxies (center object). The spectrum of the shadow from the intergalactic gas tells researchers about the chemistry, temperature, and other properties of the gas. Using this technique, the team found new evidence that the growth of a massive black hole in one distant galaxy may be preventing the birth of new stars.
Image courtesy John Strom

the researchers were intrigued to find this gas outside the galaxy. Equally astounding, portions of the cloud were traveling at high velocity, 2 million miles per hour—fast enough to escape the gravitational pull of the galaxy. The researchers wondered how the gas reached such great distances from the galaxy and how it could have been accelerated to such a high speed.

The scientists made a seven-hour observation of the galaxy's spectrum with the FIRE spectrograph on the Magellan Baade telescope. The spectrum of light from distant objects can tell researchers about its chemistry and temperature, among other properties.

This spectrum revealed that the background galaxy hosts a growing supermassive black hole, a mini quasar. They believe that it must have launched an enormous wind that drove the molecular gas out of the galaxy at high velocities.

These observations provide tantalizing evidence that the growth of a supermassive black hole can eject the raw material for star formation, dramatically affecting star formation within the galaxy. Rudie's ongoing work focuses on learning how winds driven by star formation can impact the evolution of more common distant galaxies.

Astronomy

Continued

“The team hopes to provide an independent estimate of the dark energy content of the universe.”

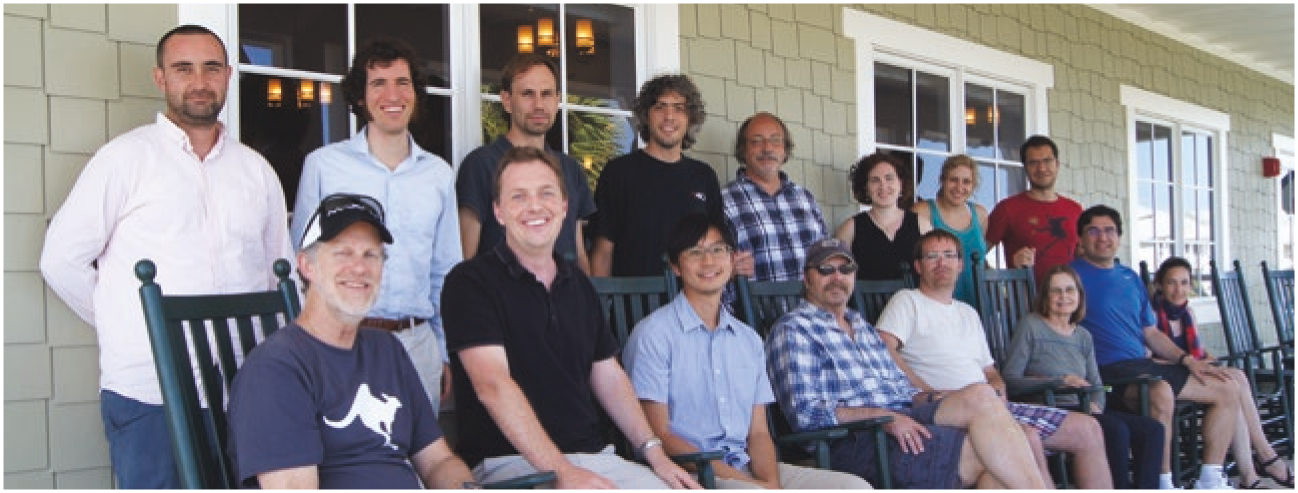
In Hubble’s Footsteps: Probing the Expansion of the Universe with Supernovae

Carnegie’s legacy of probing the size and expansion of the universe is extraordinary. It started with Edwin Hubble’s discovery in the 1920s of the expanding universe and continues today with the Carnegie Supernova Project (CSP).

Carnegie astronomers involved in the CSP include Mark Phillips, former director of the Las Campanas Observatory (LCO); Anthony Piro, The George Ellery Hale Distinguished Scholar in Astrophysics; and Chris Burns, research associate. They follow an impressive Carnegie heritage.

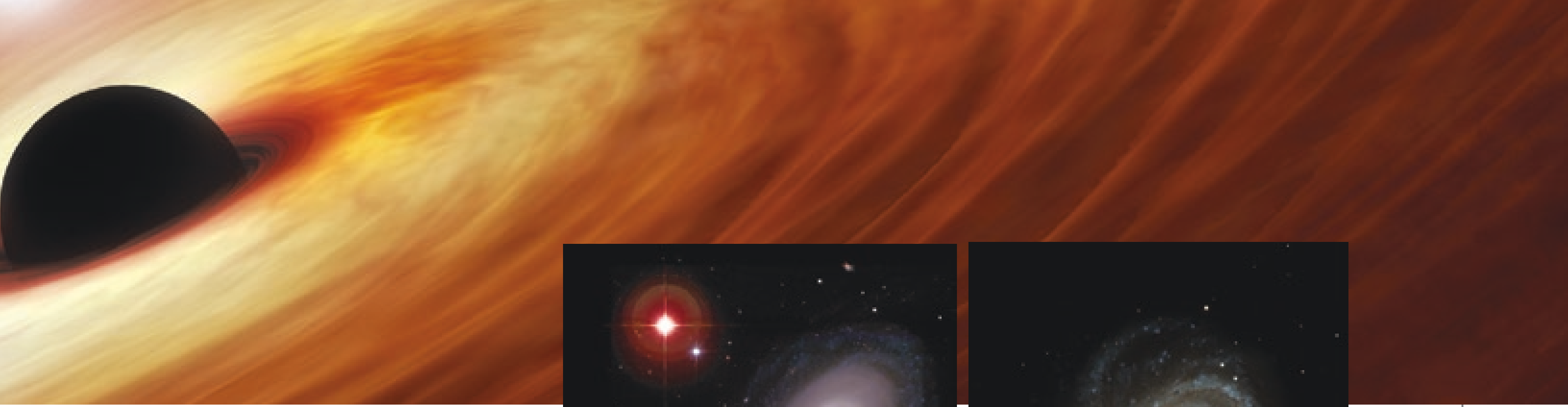
After Hubble’s discovery of the expanding universe, Walter Baade and Rudolph Minkowski showed in the 1930s that certain supernovae, brilliant stellar explosions that persist for weeks, were similar in duration and variation. They also had similar spectra, signature wavelengths revealing chemistry and age.

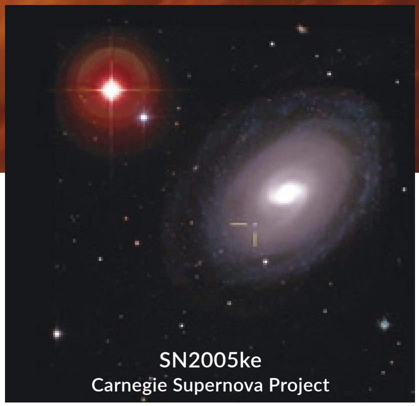
In 1939, Carnegie’s Olin Wilson suggested that super-bright supernovae from two-star systems, now called Type Ia supernova, could be used to study the expanding universe. In the 1980s, sensitive digital detectors made this practical.



The Carnegie Supernova Project (CSP) group poses for a photo at one of their meetings. Mark Phillips is in the front row, left, with Chris Burns next to him. Anthony Piro is in the back row, third from left.

Image courtesy Mark Phillips



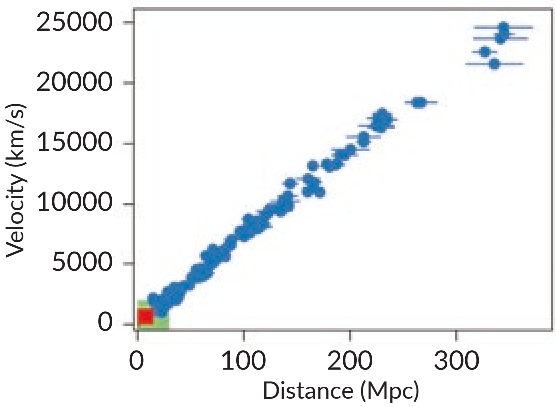


Two Type Ia supernovae, shown here, were observed by the Carnegie Supernova Project. The locations of these exploding stars in their different host galaxies are marked with yellow bars.
Color composite images by CSP postdoc Carlos Contreras

Carnegie's Allan Sandage encouraged astronomers, including Mark Phillips, to study the expansion of the local universe using Type Ias in the early 1990s. Phillips devised a method to measure distances to these objects with 10% or better precision. He was also a member of one of the two teams who found in 1998 that the expansion of the universe is accelerating. That discovery pointed to a repulsive force called dark energy.

Using near-infrared and visual observations, the goal of the CSP is to improve the precision of Type Ia supernova distances to better than 5%. Infrared is crucial. It penetrates obscuring dust for better accuracy. Since inception, the project has used nearly 2,000 nights on the LCO's 1-meter Swope telescope and over 300 nights on the 2.5-meter du Pont telescope to monitor more than 300 Type Ia supernovae.

Chris Burns heads a CSP effort to publish the most precise Hubble diagrams, depicting velocity and distance, using the first five years of data. Observations also reveal how the explosions occur and much about the stellar systems. Anthony Piro models how the brightness increases at the onset of explosion to track the distribution of radioactive nickel in the ejecta powering the fireworks. The team hopes to provide an independent estimate of the dark energy content of the universe. All of this work lays the foundation for NASA's new Wide Field Infrared Space Telescope, which will probe dark energy in the coming year.



Carnegie's Edwin Hubble discovered in the 1920s that the universe is expanding. The red square on the diagram indicates how far out he could observe, using Cepheid variables as so-called standard candles. Since then Carnegie has had a long legacy of measuring the velocity and distance of standard candles to refine the Hubble Constant, which is the rate of the expansion of the universe.

Carnegie astronomer Wendy Freedman and team refined the Hubble Constant in 2001 using the Hubble Space Telescope to reach more distant Cepheid variables (green box). Today, the Carnegie Supernova Project observes the velocity versus brightness of much brighter, and hence more distant, standard candles—supernovae (blue points). The conversion of brightness to distance requires observations of supernovae in nearby galaxies where Cepheid variable stars can be used to measure the distance independently, serving as calibrators. There are about 20 such calibrators available, seven of which were observed by the CSP with the same telescopes and detectors, with the data processed in the same manner to reduce systematic errors.
Image courtesy Mark Phillips

The Carnegie Academy for Science Education & Math *for* America

Teaching the Art of Teaching Science and Math

"11 Network Ambassadors reached more than 16,000 students, families, and educators."

Carnegie Academy for Science Education Strengthens STEM

The Carnegie Academy for Science Education (CASE) bolstered its Science Technology Engineering and Mathematics (STEM) education program in two areas this year: a strengthened partnership with the University of the District of Columbia (UDC), and a new initiative within the DC STEM Network. The latter connects educators, industry experts, community organizations, and colleges to support STEM learning across the city. The network was formed in 2014 through a partnership between CASE and the D.C. Office of the State Superintendent of Education.

The STEM education partnership with UDC began in 2008. In 2012 and 2015, CASE collaborated with the UDC College of Arts and Sciences to develop and secure two National Science Foundation (NSF) Noyce grants. The current grant, Project Firebirds Reinventing STEM Teaching (Project FRST), strengthens middle school science teaching and learning by training 20 new science teachers in Washington, D.C. CASE provides an extended internship for these teachers in training. To support them throughout their first four years as D.C. teachers, CASE designs and provides training for teacher mentors. These mentors are experienced science teachers who provide monthly in-school observations and guidance.

In April 2017, the UDC College of Arts and Sciences presented CASE with the Community Partner Award. The college selects a community partner to receive special honors for outstanding community service and best practices in leadership, development, service, and education. This year CASE was selected. UDC

The Carnegie Academy for Science Education hosted the second annual DC STEM Summit in November 2016.

The Carnegie Academy for Science Education Summer STARS program brings students and teachers together to learn STEM through hands-on experimentation in the field of astrobiology. Astrobiology deals with what sparked life on Earth and where it might be found elsewhere in the galaxy. Acting director of CASE, Marlena Jones, assists a student in the lab.
Image courtesy Blonde Photography

also hosted CASE's Summer STARS (Student-Teacher Astrobiology Researchers) and First Light student programs, while Carnegie's administration building underwent renovation. The Summer STARS program brings students and aspiring teachers together to learn STEM through hands-on experimentation.

This year, the DC STEM Network also launched the Network Ambassador Program. This is a group of community connectors from schools, extracurricular programs, and STEM enthusiasts who were recruited and trained on DC STEM resources to increase access to STEM in their D.C. communities. Network Ambassadors take their STEM training to their communities and share the knowledge, amplifying the reach of STEM programs.

Each month, ambassadors help connect at least 25 D.C. students, families, and educators to STEM resources. During this first year of the program, 11 Network Ambassadors reached more than 16,000 students, families, and educators. The network recently launched a second cohort of ambassadors to continue increasing access to STEM learning in the city.

The Carnegie Academy for Science Education & Math *for* America

Continued

Math *for* America DC founder Maxine Singer (left) and Director Bianca Abrams (right) welcomed new Fellows from Cohort III to Carnegie at a meeting in the headquarters' boardroom.
Image courtesy MfA DC

Math *for* America Establishes a Legacy

Almost a decade old, Math *for* America DC (M*f*A DC) is establishing an impressive legacy. Founded in 2008 by Carnegie president emerita Maxine Singer, M*f*A DC includes two programs, the Teaching Fellowship and the Master Teacher Fellowship. In the ten years, M*f*A DC has recruited and retained over 50 Washington, D.C., math teachers who have taught over 20,000 students. Many have received prestigious awards.

The highly selective Teaching Fellowship offers tuition scholarships and a stipend for a one-year master's degree, followed by a four-year teaching commitment in Washington, D.C., public or charter schools. In 2019, the final cohort of fellows will

Master teacher Noelani Davis is a curriculum writer with the Bill & Melinda Gates Foundation.
Image courtesy Caroline Blair

“M*f*A DC has recruited and retained over 50 Washington, D.C., math teachers who have taught over
20,000 students.”

From left, Master Teacher Tosin Ogunsile and fellows Dan Oldakowski, Derrick Simmons, and Chris Rowe participated in a kick-off event at the National Building Museum last summer. The teachers generated and solved mathematical questions inspired by the Icebergs exhibit there.
Images courtesy Caroline Blair

graduate. Thirty-six teachers will have completed the fellowship.

The goal of the Master Teacher program is to encourage teachers to remain in the classroom and to establish a community of passionate and outstanding math teachers. Master Teachers have an educational background in math, have taught math for at least four years, and have exceptional leadership qualities. They commit to teaching for five years in D.C., and they receive a stipend and extensive professional development and support. Thus far, seven M*f*A DC fellows have become Master Teachers.

Additionally, two of the four teachers who completed the Master Teacher program renewed their fellowship, committing to ten years total of teaching with support from M*f*A DC. The Master Teachers have been teaching from six to over 20 years with an average teaching experience of nine years. As a comparison, teachers in D.C. public schools (DCPS) teach for only two years on average.

M*f*A DC owes its success to the professional community, growth, and recognition. M*f*A DC teachers attend and present at national and international teaching conferences. In the 2016-17 school year, seven served as math department heads thanks to their subject matter expertise and leadership. Four of them served as leaders in DCPS's new LEAP initiative to help teachers align their teaching to the Common Core State Standards.

M*f*A DC teachers have been recognized with honors, including the DC Teacher of the Year, the Presidential Award for Excellence in Mathematics and Science Teaching, and the highly selective National Board Certification in Mathematics. Master Teacher Noelani Davis is a curriculum writer with the Bill & Melinda Gates Foundation. Several teachers have attended the Institute for Advanced Study/Park City Mathematics Institute's Teacher Leader Program, and Master Teacher Will Stafford was an instructor for this year's program.

Earth/Planetary Science

Understanding the Formation and Evolution of Planets

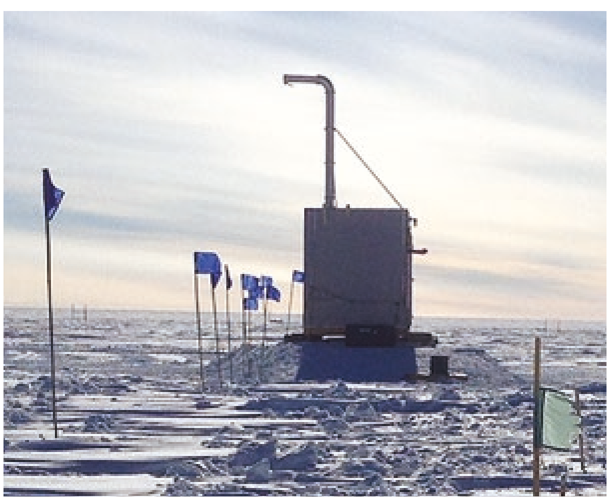
"...have devised a faster, cheaper system to collect extraterrestrial dust samples..."

Cosmic Dust Buster Debuts at South Pole

Scientists reconstruct how our Solar System formed by analyzing materials from meteorites and comets. These remnants of early Solar System history preserve chemistry from over 4.5 billion years ago, when the Solar System was only a rotating dusty, gaseous disk around the young Sun. Scientists collect meteorites from the sites where they fall to Earth, sample comets via spacecraft, and intercept interplanetary dust particles (IDPs) in the stratosphere with aircraft. Now researchers, led by Susan Taylor of the Cold Regions Research and Engineering Laboratory with Carnegie's Conel Alexander and Larry Nittler, have devised a faster, cheaper system to collect extraterrestrial dust samples from the pristine air at the South Pole.

The project is designed to collect a range of cosmic dust, including IDPs and rare ultra-carbonaceous micrometeorites from comets. The system should yield many times more particles for a fraction of the cost of airborne or space missions. This method is also preferred over collecting and melting snow because it eliminates particle/water contact, thus preserving water-soluble materials.

NASA's 2004 Stardust mission returned samples from the comet Wild 2 for analysis on Earth. That mission provided a baseline for comparing other cometary samples. Recently, researchers verified that some particles from melted Antarctic snow are indistinguishable from stratospheric IDPs; they both have high porosity and abundant organic matter, fingerprints of the earliest stages of planet formation.



The cosmic dust buster is installed south of the Clean Air Sector of the South Pole station. The air is particularly clean there because of a lack of upwind human activity or rocks. Other contributing factors include the low pressure of the tropopause, the layer just under the stratosphere; a lack of deep atmospheric convection; and the high altitude (almost 10,000 feet). The air intake is several meters above the station to avoid windblown snow.

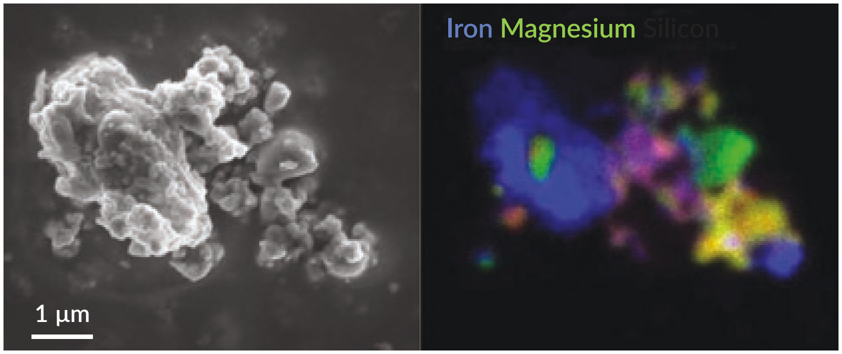
Image courtesy Susan Taylor

Conel Alexander (left image) arrives at McMurdo Base Antarctica on his way to the South Pole. Larry Nittler (right image, left) participated in a NASA/NSF meteorite collecting expedition in Antarctica in 2000-2001; here he is securing a meteorite. Antarctica is a good place to find meteorites because glaciers concentrate them in certain areas, the thick ice sheet ensures there are few terrestrial rocks, and their dark coloring stands out against the snow and ice.
Images courtesy Conel Alexander and Larry Nittler

The new collector intake system is elevated a few meters above the surface to minimize snow intake and permit year-round collection. The goal is to collect 300–900 IDPs per month. The particles are typically 5-50 micrometers (µm) in size.

In late 2016, the team designed, built, tested, and deployed the Antarctic instrumentation. In 2017, they collected four test filters. One was exposed for five hours, another for six days, while the other two were exposed for a month each.

Despite some terrestrial contamination, which is easily distinguished from extraterrestrial material, cursory examinations revealed a couple of extraterrestrial particles for analysis. The team started a survey of the most promising of the four filters, and will be retrieving filters throughout 2017-2018. If the cosmic dust buster system is successful, it will complement NASA's Antarctic meteorite collection program and will be a tremendous asset for researchers interested in studying the most primitive materials in the Solar System.



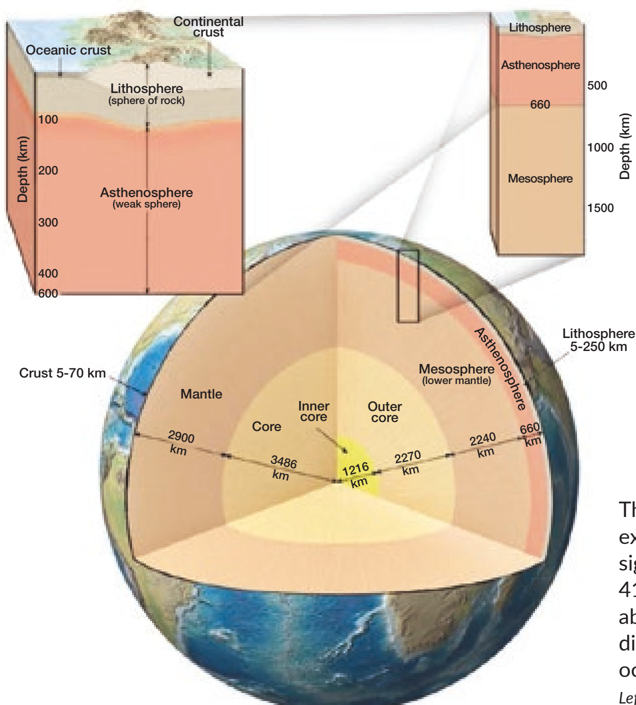
This image shows one of the first Interplanetary Dust Particles (IDPs) collected by the South Pole dust buster. A scanning electron microscope image shows its fine-grained, porous structure on the left; a chemical map appears on right.
Images courtesy Larry Nittler

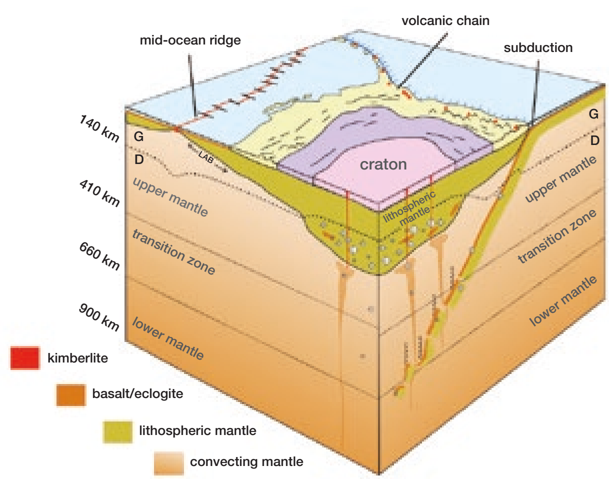
The Secrets "Superdeep" Diamonds Expose

Some diamonds, the so-called superdeep diamonds, formed deeper than 185 miles (300 kilometers) in Earth's interior. They are highly valuable for research because they are impervious capsules enclosing and protecting deep-crystallizing mantle minerals that would be otherwise unattainable. These mineral inclusions, impurities to the jeweler, help scientists understand Earth's interior, potentially revealing the chemistry, temperatures and pressures, water content, and other features of the deep mantle. New work, started by Evan Smith at the Gemological Institute of America, with Carnegie's Steve Shirey and colleagues, is using these unique diamond features to unravel conditions in the deep mantle.

> "…unlike all other diamonds, they contain small iron-nickel metal inclusions, a compound that is extremely rare in natural materials in the shallow Earth."

The researchers use various instruments to analyze diamonds and their tiny impurities. Mass spectrometry measures the relative abundance of isotopes, atomic siblings with different numbers of neutrons. Electron probe microanalysis reveals elemental compositions of





The Earth's mantle, just below the crust, has three layers. The upper mantle extends to about 255 miles deep (410 km). Material in the mantle undergoes significant transformations in the mantle transition zone, from about 255 to 410 miles deep (410 to 660 km). The lower mantle sits on top of the core from about 410 to 1795 miles deep (660 to 2890 km) The depths for superdeep diamonds can be seen on the second diagram on the right side, where a oceanic lithosphere is sinking into the deep Earth.

Left images courtesy Tasa Graphic Arts, Inc.; right image courtesy Steve Shirey adapted from Tappert and Tappert, Rough Diamonds, Cambridge.

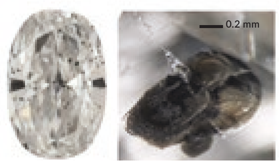
Students pose at the Diavik diamond mine in the Lac de Gras area in Canada. This area is known for occurrences of diamond-bearing kimberlite volcanic rock, which carry shallower diamonds as well as the superdeep types. The University of Alberta's Graham Pearson, Carnegie's Steve Shirey, and the University of Padua's Fabri Nestola organized the diamond school there.
Image courtesy Steve Shirey

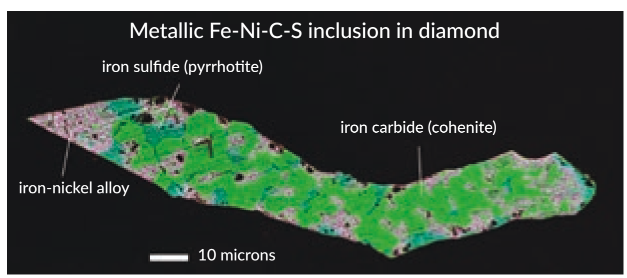
the minerals. Carbon isotopes in the diamond capsule reveal whether it contains recycled surface material. Raman spectroscopy uses lasers that are focused microscopically to identify the frequency of molecular vibrations for identifying the mineral grains and any fluids present that will indicate the conditions under which they crystallized.

Importantly, the team discovered that a certain class of the highest purity, largest diamonds known, and never before available for study, formed from metallic liquid deep in the mantle. The researchers conclude this origin because, unlike nearly all other diamonds, they contain small iron-nickel metal inclusions; such metallic compounds, common in certain classes of meteorites are extremely rare in rocks in the shallow Earth.

On Earth, regions of the near-surface mantle contain more oxygen, while deeper down the activity of oxygen is reduced. These rare, superdeep diamonds provide an indirect look at deep mantle oxygen-reduced conditions that could only have been theorized previously, but can now be sampled. Such oxygen-reduced regions could shed light on the relationship of the mantle to the core, show that the mantle is much more mineralogically inhomogeneous than thought, and give scientists new evidence on how carbon is stored and moves around that region.

Surprisingly, some of the diamonds with metal inclusions also carry silicate minerals with affinities to a high-pressure form of the volcanic rock basalt, called eclogite. Many of these diamonds are deficient in carbon-13, the heavier stable isotope of carbon. Both features tie oxygen-reduced mantle regions in the deep mantle to the recycling of organic-rich surface material into Earth's interior driven by plate tectonics, which this new diamond research now allows scientists to explore in detail.

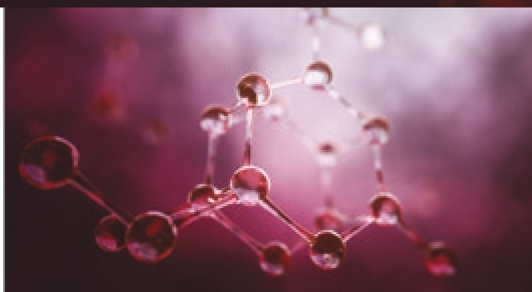




A superdeep diamond, faceted into a gemstone with mineral impurities is shown top left, with a close-up of the impurity (top right) At bottom, an iron-nickel-carbon-sulfur-bearing inclusion in a superdeep diamond from the Letseng Mine, South Africa, shows the typical mineral assemblage in these impurities that crystallizes when the diamond is erupted to the surface. Black in this false-color, electron microscopy image is the host diamond. When at high temperature and pressure in the mantle, this inclusion was a single metallic liquid. Ten microns is 10 millionths of a meter or less than half the width of a human hair.
Image courtesy Evan Smith

Genetics/Developmental Biology

Deciphering the Complexity of Cellular, Developmental, and Genetic Biology



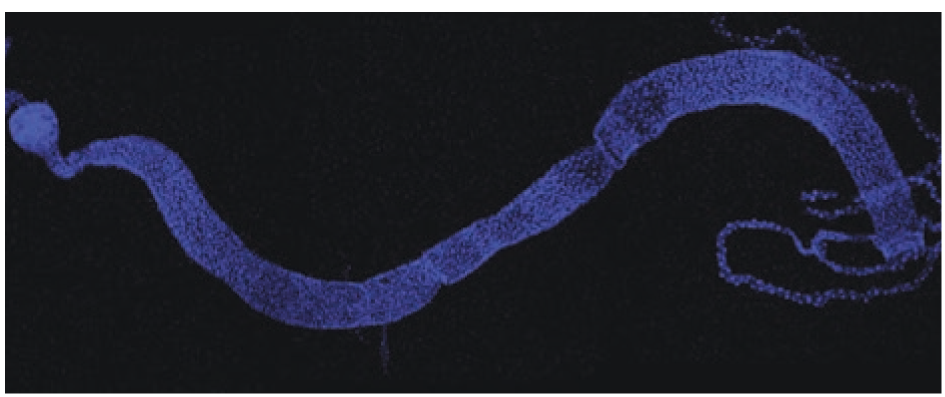
"Unexpectedly, the scientists also found that depriving flies of cholesterol also **blocks the formation of intestinal tumors...**"

Cholesterol Can Change Gut Cell Identity and Cancer Susceptibility

The food we eat provides the protein, sugar, and lipids that cells need to grow, divide, and function. However, depending on what food you eat, the amount of these nutrients varies dramatically. As a result, organisms ranging from bacteria to humans must adapt to changes in dietary nutrition. Dietary changes, such as eating a diet high in fat, can also have a major influence on human health and lead to disease, such as diabetes, and increase a person's risk for some cancers.

Surprisingly, work from Carnegie's Rebecca Obniski, Matt Sieber, and Allan Spradling found that changes in dietary cholesterol could alter the identity of cells in the intestine. The group uses the fruit fly, *Drosophila melanogaster*, as a tool to understand mechanisms that control intestinal stem cells in many organisms. The simple fly intestine is made up of three cell types: stem cells, hormone-producing cells, and nutrient-absorbing cells called enterocytes. The group found that depriving young flies of cholesterol causes stem cells to produce more absorptive enterocyte cells and fewer hormone-producing cells. Conversely, they found that increasing dietary cholesterol causes stem cells of young flies to produce significantly more hormone-producing cells at the expense of enterocytes.

The group discovered that cholesterol affects intestinal stem cells by controlling a protein called Hr96, which senses cholesterol and controls the cell's response to dietary cholesterol. Hr96 and cholesterol, in turn, regulate the cascade of molecular signals called the Notch signaling pathway, which has well-



This microscopic image shows a normal fruit fly intestine.

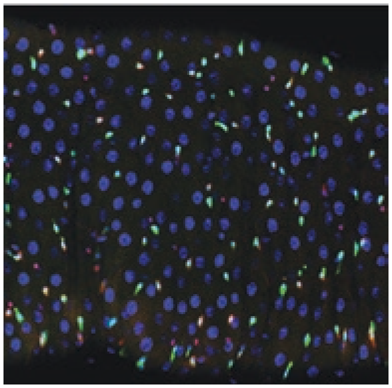
characterized roles in controlling cell fate and the onset of cancer in many tissues.

Interestingly, they found that cholesterol regulates Notch signaling in other tissues as well as in human cell lines. This result indicates this pathway dates back evolutionarily to control cell identity in response to diet throughout the animal kingdom.

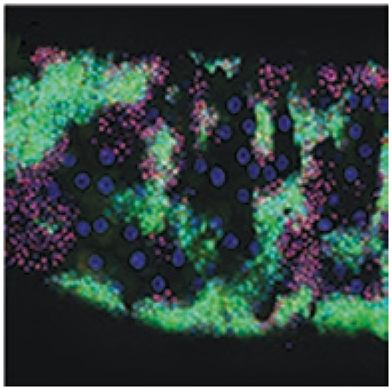
Unexpectedly, the scientists also found that depriving flies of cholesterol also blocks the formation of intestinal tumors, suggesting that the amount of cholesterol in the diet may dictate the risk of many cancers in humans.

This work additionally shows that the fly intestine system allows researchers to gain real functional insight into the effects diet has on stem cell biology in general. This system also allows them to better understand the mechanisms that underlie the relationships between diet and disease that are emerging from clinical studies.

Matt Sieber (back left), Rebecca Obniski (front left), and Allan Spradling conducted the work on the effects of cholesterol on gut cells and tumor growth.
Images courtesy Matt Sieber



This image shows a section of fly intestine prior to tumor formation. Blue areas are cell nuclei; pink are endocrine cells; and green are defective cells in the molecular signaling pathway called Notch.



This image shows a section of a fly intestine with several large tumors in green that grew because of the defective Notch signaling pathway. Blue indicates cell nuclei, while pink indicates endocrine cells.

Genetics/Developmental Biology

Continued

How Fish Swim Again After Freezing in Fear

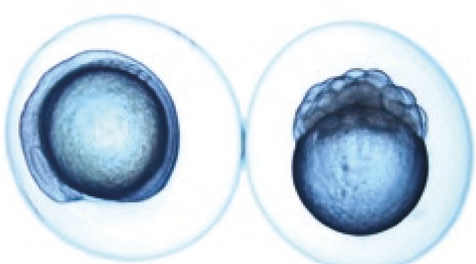
The brain is the body’s mission control center, sending messages to the other organs about how to respond to various external and internal stimuli. Located in the forebrain, the habenular region is one such message-conducting system. New work from Carnegie’s Erik Duboué and Marnie Halpern, assisted by Kiara Eldred, a Johns Hopkins graduate student, and Elim Hong, now at the Institut de Biologie Paris-Seine, focused on the action of the habenular region in regulating fear responses in larval zebrafish.

> “The link between the asymmetrical nature of brain function and responses to fear or anxiety may be a general feature of the vertebrate brain.”

All vertebrates have the bilaterally paired habenulae, which influence the release of dopamine and serotonin, two important chemicals related to motor control, mood, and learning, by other regions of the brain.

Previous research showed that the habenular system is involved in modulating sleep cycles, anxiety, and pain and reward processing, among other things. It has also been associated with depression and addiction.

It turns out that the habenulae differ between the left and right sides of the fish brain, both in their structure and when it comes to experiencing and recovering from fear. A mild electric shock makes zebrafish larvae freeze in fear, like a deer in headlights. Afterward, the team found that neurons in the left habenula are needed for a rapid return to swimming activity.



Zebrafish are widely used for developmental studies. The young fish is entirely clear, allowing researchers to monitor development in real time. These live embryos (top) reside within egg membranes. The one on the left is about 12 hours old. You can see the developing eye at about the 7 to 8 o’clock position. The one on the right is a 32-cell stage embryo, less than 2 hours after fertilization. Adult zebrafish are shown swimming in a tank at Carnegie’s aquatic facility (left).

Images courtesy Marnie Halpern and Jeremy Hayes

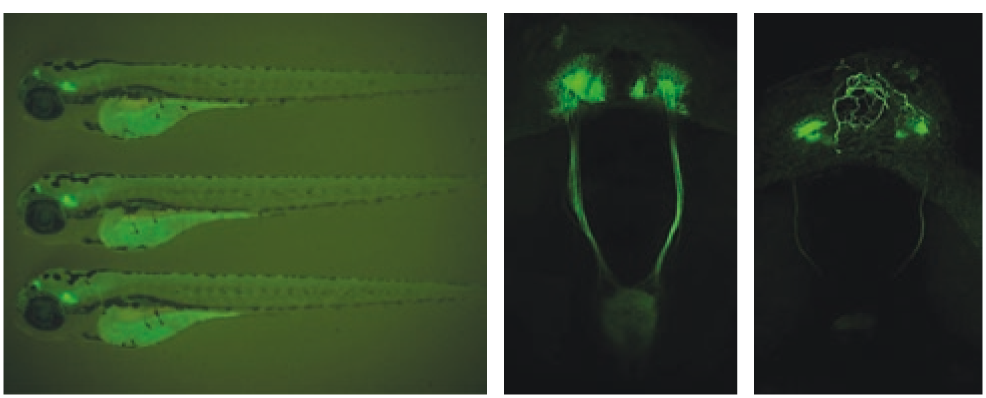
Members of the Halpern lab in July 2017 are shown. Back row (from left): Jean-Michael Chanchu, Carolyn Winston, Erik Duboué, Ji Cheng, Michelle Macurak. Front row (from left): Amanda Chicoli, Joselyn Stibalis Yamamoto, Jung-Hwa Choi, Neta Shwartz.
Image courtesy Connie Jewell

The link between the asymmetrical nature of brain function and responses to fear or anxiety may be a general feature of the vertebrate brain. One provocative hypothesis proposes that positive and negative stimuli are differentially processed by the left and right sides of the brain. Duboué will probe this idea further in his own new lab at Florida Atlantic University.

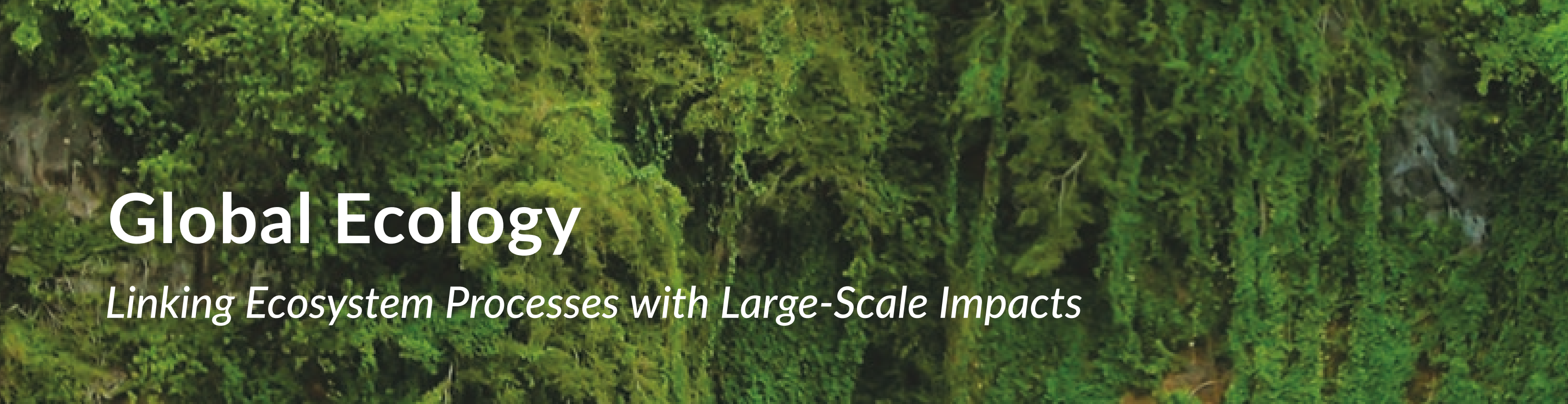
This research, and work from other groups, shows that the habenular region is a critical integrating center for relaying information between brain areas. But, until recently, much remained unknown about how this region develops.

Another study from Halpern and Sara Roberson, a recent Ph.D. graduate, describes how a network of extracellular signals ensures that the habenular region successfully forms during zebrafish development. Remarkably, these early signals are also essential for setting up the molecular cues that later guide mature habenular neurons towards their correct targets.

When signaling is disrupted early, the habenular pathway will not be properly wired, which has consequences on the transmission of information throughout the brain.

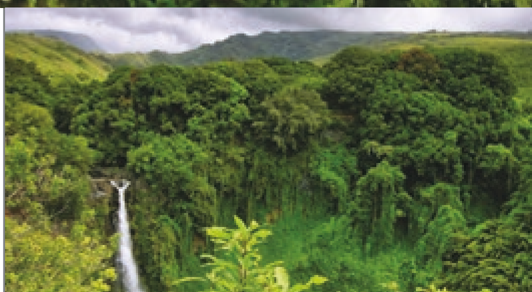


The left image shows larval zebrafish with glowing habenular neurons in the forebrain connected to their midbrain target.The middle image is a close-up of these neuronal projections on both sides of the brain. On the right, in a mutant brain with abnormal signaling, habenular neurons are misrouted and many fail to connect with the midbrain.
Images courtesy Courtney Akitake and Sara Roberson



Global Ecology

Linking Ecosystem Processes with Large-Scale Impacts



"They. . . found that calcification rates under preindustrial conditions were higher than today."

First Ocean Experiment Confirms Corals' Decline from Acidification

It has been hard to pinpoint how much of the decline of the ocean's corals is due to acidification because warming, pollution, and overfishing all play a role. However, a team led by Rebecca Albright (formerly a Carnegie postdoctoral fellow, now with the California Academy of Sciences) and Ken Caldeira recently performed the first-ever experiment that manipulated seawater chemistry in a natural coral reef to determine the effects of carbon dioxide released by human activity. They confirmed that ocean acidification is slowing coral reef growth.

The team is shown in this group shot on One Tree Island. Lead author Rebecca Albright is third from right. Ken Caldeira is second from left. Albright (now with the California Academy of Sciences) and Caldeira performed the first-ever experiment that manipulated seawater chemistry in a natural coral reef to determine the effects of carbon dioxide released by human activity. The work was conducted off Australia's One Tree Island in the southern Great Barrier Reef.
Image courtesy Ken Caldeira

Greenhouse gas emissions affect the atmosphere and the world's oceans. This is partially due to ocean warming caused by climate change. However, atmospheric carbon dioxide also reacts with seawater, forming a corrosive acid that dissolves coral reefs, shellfish, and other marine life in a process called ocean acidification.

Coral reefs are particularly vulnerable to ocean acidification, because reefs are built by calcium carbonate accretion (calcification), which becomes increasingly difficult as acid concentrations increase. Scientists predict that acidification could cause reefs to switch from accreting carbonate to dissolving it within the century.

Caldeira's group tried to experimentally add alkalinity, using lye, to seawater flowing over a natural coral reef to manipulate acidification for several years. Albright led the third attempt, which was the first successful one, off Australia's One Tree Island in the

southern Great Barrier Reef. They brought the reef's pH close to the preindustrial period level based on estimates of preindustrial atmospheric carbon dioxide. They measured the reef's calcification in response to the pH increase and found that calcification rates under the preindustrial conditions were higher than with unmodified seawater.

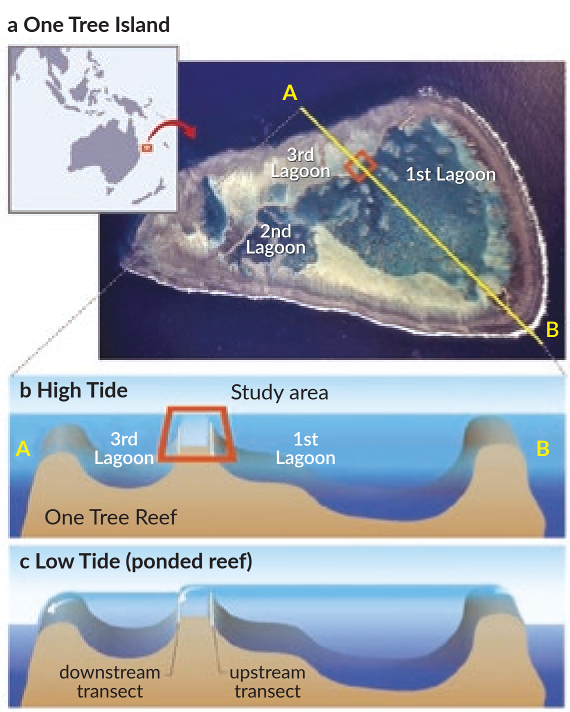
Previous studies demonstrated large-scale declines in coral reefs over recent decades. Work from another team led by Caldeira found that rates of reef calcification were 40 percent lower in 2008 and 2009 than they were during the same season in 1975 and 1976.

The newer work provides the first strong evidence from experiments on a natural ecosystem that ocean acidification is already slowing coral reef growth and damaging reef communities.

Increasing the alkalinity of ocean water around coral reefs has been proposed as a geoengineering measure to save shallow marine ecosystems. These results show that this idea could be effective, but it would be virtually impossible at all but the smallest scales, making cutting our carbon dioxide emissions critical to reef survival.

One Tree Island is shown from the air in the top left image. The diagram shows how the study area provides a natural laboratory for the experiment of dialing back the carbon dioxide concentration to see if it stimulates calcification. Researchers are shown working on that reef in the top right photo.

Images courtesy Ken Caldeira



Global Ecology

Continued

The Spectranomics' Decade: Huge Boost to Science and Conservation

"... a database of about half of the world's known tropical canopy species"

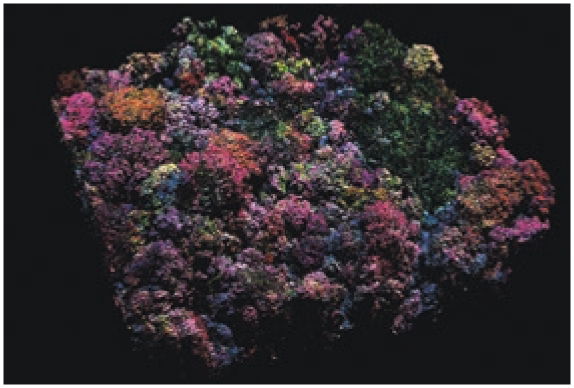
The Carnegie Spectranomics Project just celebrated ten years! The pioneering venture uses the fixed-wing Carnegie Airborne Observatory (CAO) to detect reflected light, spectra, from fully sunlit tropical plant canopies below. The team confirms the data by collecting and analyzing canopy foliage on the ground to reveal chemical fingerprints, leaf structure, and different species in unprecedented detail. Over the last decade the group has created a database of about half of the world's known tropical canopy species.

Traditional satellite observations do not easily reveal compositional differences or changes over time, but spectranomics can. It represents a new pathway for science and conservation mapping.

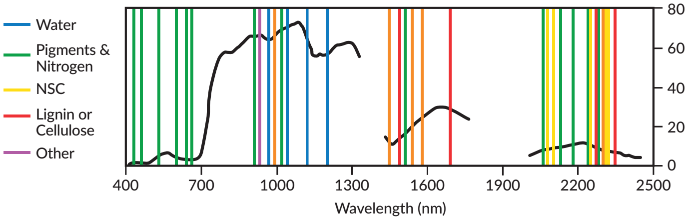
Greg Asner and Robin Martin started the project 10 years ago in a remote valley on Kauai, Hawaii. Over time, Martin developed the spectranomics' foliar laboratory and archives, now a world-class facility at Carnegie. Other labs have emulated it, and the project has become the foundation for a new satellite mission called The Life Mission, led by Asner. This mission will be the CAO in orbit, enhancing analysis at the planet level.

Thus far, the Martin team has cataloged, analyzed, and stored more than 13,000 canopy tree and woody vine specimens, in over 3,000,000 tissue samples. The archive comprises about 10,000 tropical forest species from Latin America, Australia, South Africa, Malaysia, Madagascar, and the United States.

Canopy Functional Traits & Composition

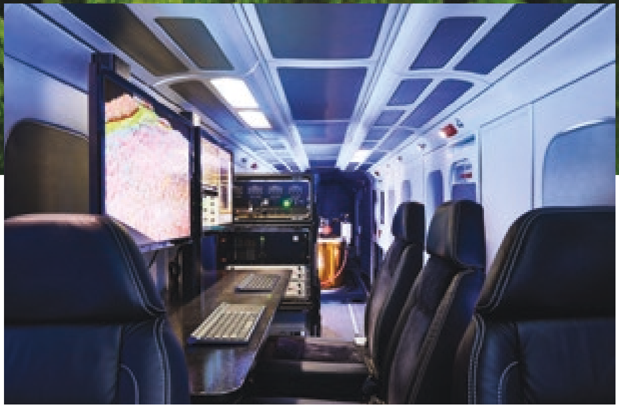


Remote Sensing with Imaging Spectroscopy



The image to the left shows the 3-D structure and chemistry of a swath of tropical canopy. Different colors represent the different chemistries of the vegetation. The top image shows different chemical fingerprints revealed by the reflected light spectra.

Images courtesy Greg Asner



Robin Martin, Carnegie staff associate, Greg Asner, and their team use spectral data of tropical canopies from the flying laboratory housed in the Carnegie Airborne Observatory-3 (top right). The team verifies the readings by collecting samples on the ground (left). Over the last ten years they have analyzed, cataloged, and stored over 3-million tissue samples (bottom).
Images courtesy Greg Asner

The spectral properties link plant species' geography to their functional traits—that is, how the foliage interacts chemically with the environment. These traits affect leaf processes, plant function, and ecosystem dynamics. The team studied some 21 critical elemental and molecular properties that drive plant evolution and the biosphere, such as nitrogen and photosynthetic pigments supporting growth, defense-system chemicals, and lignin, a component of wood.

The project has also uncovered linkages to the evolutionary tree of life, showing relationships among organisms tied to their spectra and chemistry. These data allow scientists to scale up from leaves to landscapes, and the planet.

There are three major emerging areas for spectranomics. First is studying how plants interact with species from microbes to predators in the biosphere. Second, spectranomics could test evolutionary relationships with canopy traits from small to large scales, and forecast what can be mapped and monitored from afar. Finally, since conservation and management are often limited, the project could improve conservation at large scales. Spectranomics could identify high-value conservation targets for better decision-making.

Matter at Extreme States

Probing Planetary Interiors, Origins, and Extreme States of Matter

Andrew Steele leads a team developing strategies for finding evidence of life on Mars.
Image courtesy Andrew Steele

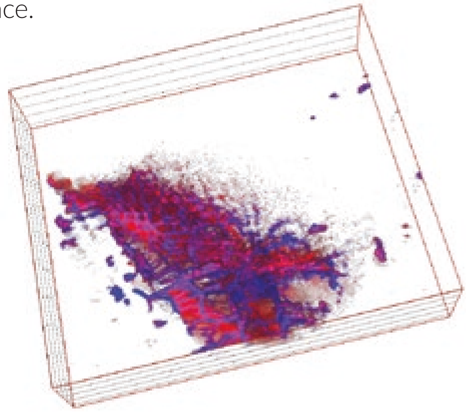
Searching for Life on Mars

Martian meteorites are rock fragments that were ejected from Mars during major impacts and then collided with Earth. They are key for developing life-detection strategies for new Mars missions. Andrew Steele and team have been analyzing meteorites to determine how best to search them for reduced organic carbon, which is fundamental to life.

Understanding the nature, sources, and sinks of this carbon is key. The researchers tackle challenges including determining whether the reduced carbon is from Mars or is contamination from Earth, and whether it came from indigenous biological or geological processes, or from material from space.

All but one of the meteorites reviewed were solidified from lava, and organic carbon was found in all but one. Several features reveal organics. Organics found in cracks or near the surface of a meteorite were dismissed as terrestrial contamination, while those lodged deep within suggest a genuine Martian origin. Subsequent chemical analysis is also crucial for confirmation.

This is the Tissint meteorite from Mars; it landed on Earth in 2011. It is unique in that it is minimally contaminated, and the presence of the organic carbon it contains is different from others of its type. The cube is one centimeter on each side.
Image courtesy Meteor Center



This is a 3-D confocal Raman imaging spectrograph image through a section of the Martian meteorite NWA 1950. Each side is about 40 microns. A micron is one millionth of a meter. These scans produce images plus the chemical composition of samples. The red indicates the presence of the titanium-iron oxide mineral ilmenite. Blue indicates veins of reduced carbon.
Image courtesy Andrew Steele

This artist's conception shows NASA's Mars 2020 mission rover. The Steele team's work on strategies for finding evidence of life on Mars will contribute to this mission, which will address key questions about the potential for past life on Mars.
Image courtesy NASA

> "Mars produced reduced organic carbon for most of its history and. . . the building blocks of life are present there."

In 2011, a new Martian meteorite fell to Earth and was quickly collected and analyzed by the team. They used multiple instruments to characterize its organic content. Contamination was less of a concern since it was freshly fallen.

This new Martian meteorite, called Tissint, contained a combination of reduced carbon and organic compounds that indicated it had formed on Mars by hydrothermal processes. Steele works with the NASA Sample Analysis at Mars (SAM) team, and he is correlating the meteorite results with investigations aboard NASA's Curiosity Mars mission. He is trying to provide a background for a life-detection strategy that does not rely on terrestrial life biases by understanding the chemical reactions, not involving life, that are possible under Martian conditions.

Steele showed that Mars produced reduced organic carbon for most of its history and that the building blocks of life are present there. The formation processes include carbon in the form of graphite that was impact generated; organic carbon/nitrogen formed by primary hydrothermal processes, from fluids present before the Martian magma cooled; and graphite formed by secondary hydrothermal processes, from fluids after the magma cooled, among others.

The team recommends that future missions consider the nonbiological chemistry on Mars, in addition to the geological context, and the use of multiple measurements, including analyzing samples returned to Earth. Importantly, all observations should be treated first as nonlife signatures until the evidence overwhelmingly suggests otherwise. Clear operating guidelines and peer review are also essential.

Matter at Extreme States

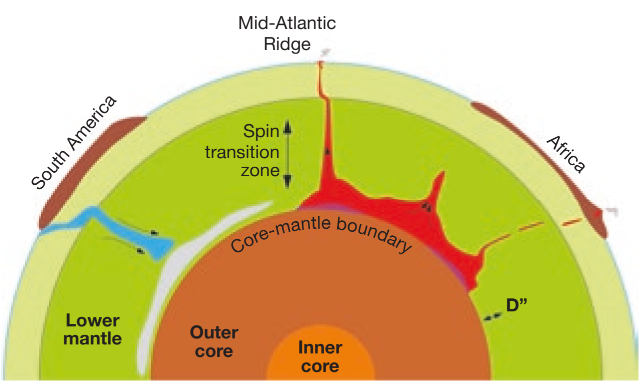
Continued

Using Lasers to Peek into the Deep Earth

Scientists can't study the deep Earth directly. But by measuring how seismic waves travel scientists can determine the consistency of the material there. They can also subject minerals to intense pressures and temperatures in a diamond anvil cell to mimic interior conditions.

The lower mantle is believed to consist mostly of two minerals: silicate perovskite ((Mg, Fe) SiO_3), also known as bridgmanite, and ferropericlase ((Mg, Fe) O). Pressures in the lower mantle range from 246,000 to 1.3 million times atmospheric pressure (25 to 135 gigapascals), and temperatures range from 3150° to 6750°F (2000 to 4000 K).

The bottom of the lower mantle is particularly interesting because complex geological processes affect convection, plate tectonics, and even the core geodynamo, which generates Earth's life-sustaining magnetic field. Alexander Goncharov, Sergey Lobanov, and Nicholas Holtgrewe recently developed a white-light laser optical spectroscopy system to vastly improve mineral measurements for this region.



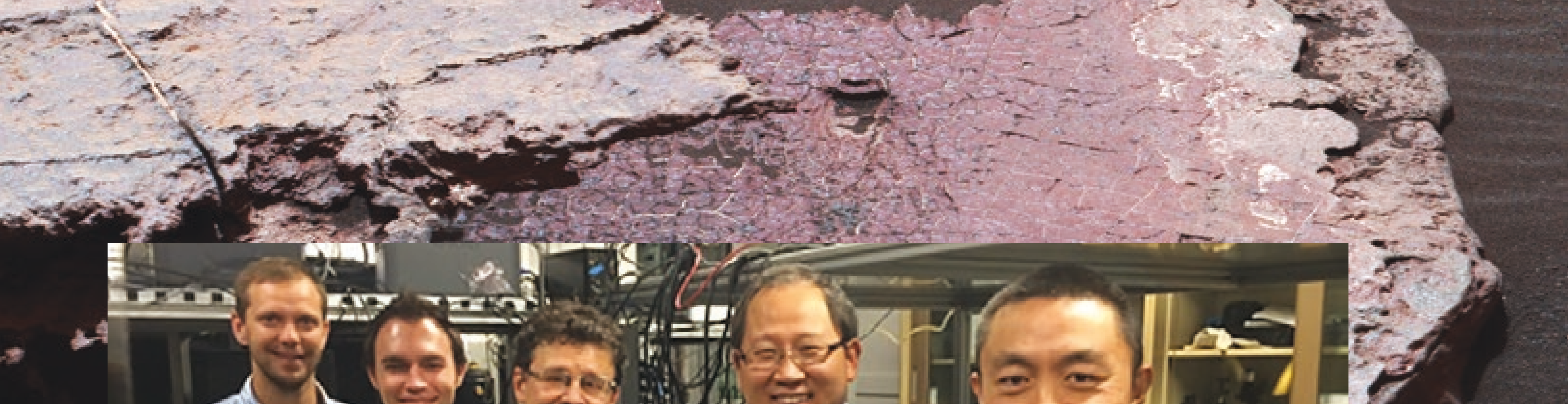
"These novel studies will likely revamp planetary evolution models."

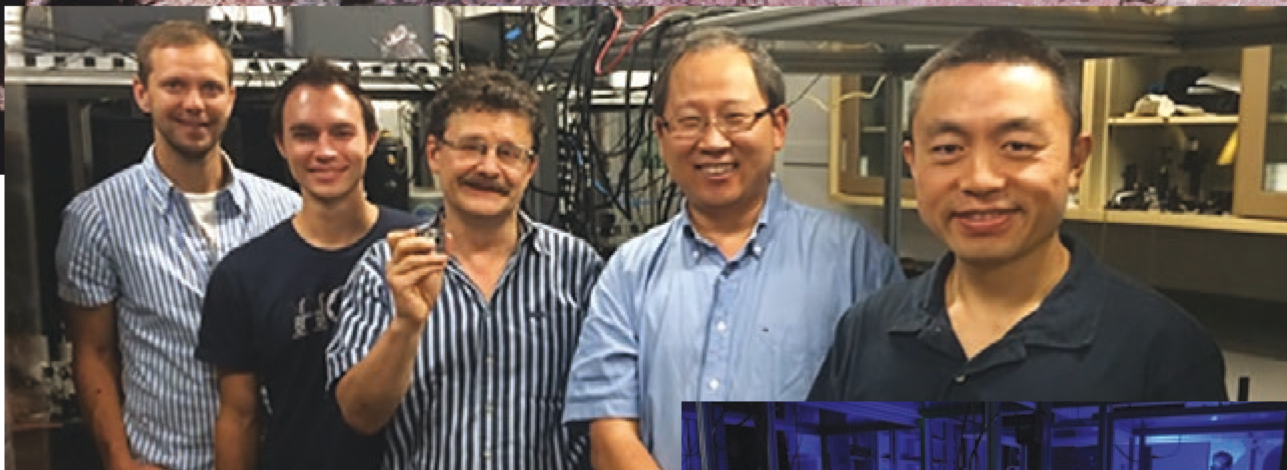
Standard optical spectroscopy is traditionally used to reveal atomic, molecular, or chemical processes. Most lasers operate under continuous irradiation and use fixed wavelengths. In the Goncharov lab, high-power "white-beam" laser spectroscopy is employed, using very short and intense bright pulses to measure multiple wavelengths simultaneously, enabling considerably more information to be obtained.

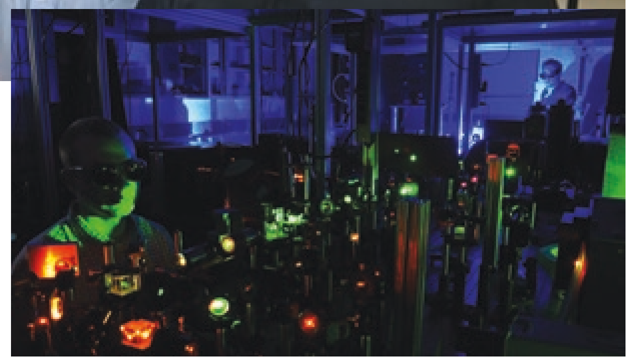
The pressures in the lower mantle squeeze atoms so close that they interact oddly, forcing electrons to change their standard configuration. This alters the so-called electron spin state of iron, which can influence lower mantle dynamics. For the first time, the new system allows the scientists to look at these spin transitions at high temperature and reconstruct the spin state of the mantle with depth.

The scientists performed optical studies on mantle minerals at temperatures greater than 5000°F (3000K)

This cutaway shows the extensive activity in the lower mantle, much of which affects dynamics at the surface. Slabs of tectonic plates (blue) sink into the deep Earth. Heat (red) drives the flow of material and magma's rise to the surface, powering volcanoes, among other forces at work.
Image courtesy Sergey Lobanov



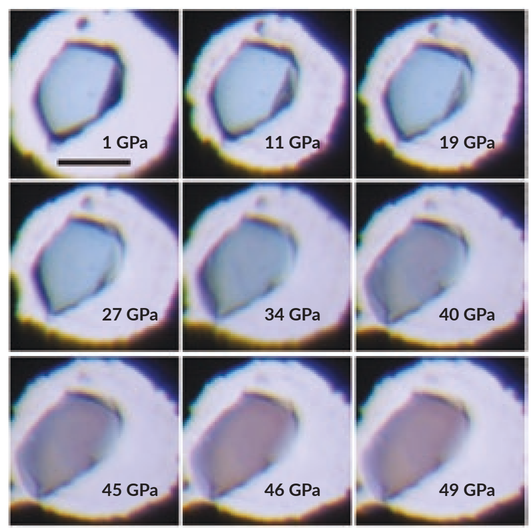




The Goncharov team poses in the lab (above). Alexander Goncharov (middle) holds a diamond anvil cell. Lab members (from left): Sergey Lobanov, Nicholas Holtgrewe, Alexander Goncharov, Xiaojia Chen, Haidong Zhang. The laser lab, at right, is pictured while experiments are being conducted.
Images courtesy of Alexander Goncharov and Sergey Lobanov

and used a new, very fast streak camera, which records spectral information almost continuously. They examined bridgmanite at 1.15 million atmospheres (117 gigapascals), simulating the core/mantle boundary zone, and surprisingly discovered bizarre behavior of bridgmanite and ferropericlase. Bridgmanite remains fairly transparent in the solid state but becomes significantly darker with melting. In contrast, ferropericlase is almost completely opaque at hot temperature, even as a solid.

This result implies that ferropericlase depresses the conductivity of radiation of the present-day Earth core-mantle boundary region. It also means that Earth was very opaque in the molten state, some 4.5 billion years ago. These novel studies will likely revamp planetary evolution models.



The researchers measured optical signatures of the iron-bearing new aluminous phase and observed a color change (blue to pink) at pressures of 345,000 to 395,000 times atmospheric pressure (35-40 gigapascals). Such changes can help understand what is going on with electron spin states as atoms are squeezed under intense pressures. These advances open the door to studying the spin states of bridgmanite and post-perovskite minerals in the lower mantle. This work will ultimately allow the scientists to reconstruct the spin state of the mantle for a better understanding of radiative heat transfer and its relationship to mantle dynamics.
Image courtesy Sergey Lobanov

Plant Science

Characterizing the Genes of Plant Growth and Development

"This treatment stimulated a **strong rooting response** and an accelerated shoot emergence from both compounds."

Cyanide Prompts Flowering After Wildfire!

Winslow Briggs, director emeritus and staff scientist at Plant Biology, is internationally renowned for unraveling the mystery of how plants respond to light for growth and development and for understanding blue-light photoreceptor systems. He was director of the department from 1973 to 1993. Briggs still runs his lab, and he works as a uniformed volunteer at Henry W. Coe State Park in California. This newer role has led to his studying how fire, particularly components of smoke, stimulates rampant flowering in some plants. He, with senior fellow Tong-Seung Tseng, surprisingly found that the slow release of toxic cyanide from a compound in wildfire smoke may drive the dramatic flowering of the triplet lily *Triteleia laxa*, which sprouts from a tuber-like structure called a corm.

Winslow Briggs and his wife Ann volunteer at Henry W. Coe State Park in California, where the 2007 wildfire inspired this research.
Image courtesy Winslow Briggs

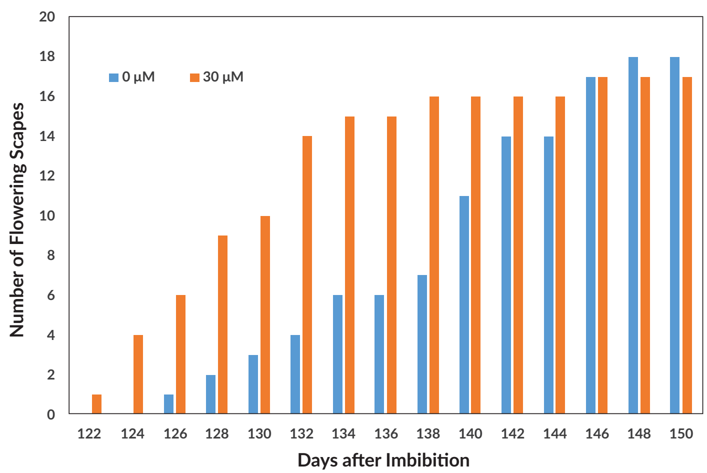
People have observed for decades that something in smoke prompts seed germination and that certain bulb and tuber-like corm plants called geophytes flower profusely the first year following a wildfire. Over the last decade researchers have isolated several different compounds involved in seed germination. One group, called karrikins, is comprised of related compounds that come from burning cellulose, essential components of plant cell walls. The other is the unrelated glyceryl nitrile, which is typically produced by burning vegetation.

The Briggs group tested one of the karrikins, karrikin 1, and then glycosyl nitrile (commercially available, with the same chemistry as glyceryl nitrile) to see if either affected root production, shoot emergence, growth

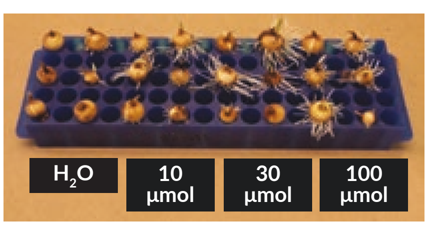
A neighbor of Henry W. Coe State Park accidentally started a fire in 2007 (right). Winslow Briggs and team used the opportunity to study how fire affects subsequent vegetation. Thousands of the triplet lily *Triteleia laxa* flowered in the following spring (far left).
Right image courtesy California Department of Parks and Recreation; far left image and top banner courtesy Robert Patrie

rate, or flowering of the *Triteleia laxa*. Karrikin 1 had no effect, but glycosyl nitrile strongly boosted root development and shoot emergence.

The researchers then subjected the tuber-like corms to water alone or to vapor from different concentrations of either potassium ferrocyanide or ferricyanide. These salts are slightly unstable under light and release trace amounts of cyanide when illuminated. This treatment stimulated a strong rooting response and an accelerated shoot emergence from both compounds. Both direct glycosyl nitrile treatment of corms and the indirect addition of cyanide as vapor for the first five days following the initiation of water absorption induced a modest but significant increase in flowering weeks later. The scientists believe that the slow release of cyanide from glyceryl nitrile following a wildfire may play an important role in the explosion of flowering in this plant.



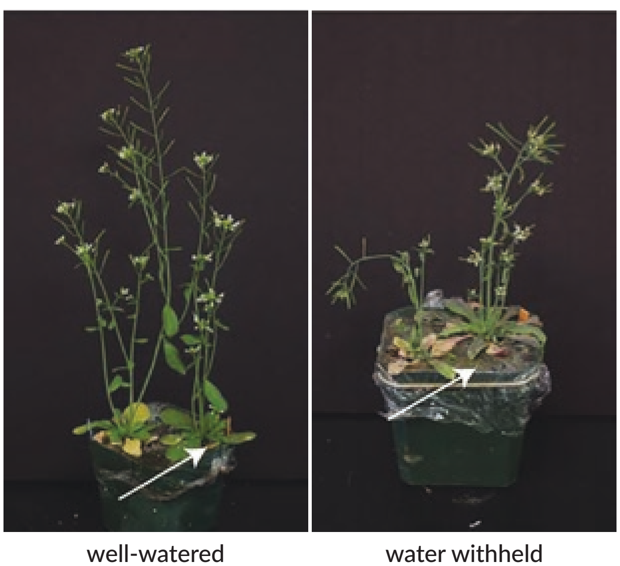
This chart shows the effect of water and water with glycosyl nitrile on the number of flowering stalks of the triplet lily *Triteleia laxa*. The compound jump-starts the flowering process for the first 140 or so days.
Image courtesy Winslow Briggs



This photo shows the tuber-like corms of the triplet lily *Triteleia laxa* with the application of water only (left two columns) 48 hours after the addition of water. Few roots proliferated. With increasing amounts of a solution of water with glycosyl nitrile, a close analog of glyceryl nitrile found in wildfire smoke, roots were increasingly abundant (the roots to the right of water-only corms).
Image courtesy Winslow Briggs

Discovering a Path to Drought-resistant Plants

Leaves are small solar power plants that turn the Sun's energy into food for the plant and for us. But there's a cost to producing and maintaining these generators, particularly a significant water cost for building and maintaining a leaf. To compensate, plants have evolved mechanisms to match the rate of leaf production and disposal to water availability. Kathryn Barton's lab found that the system linking drought stress to leaf production and disposal in the model plant *Arabidopsis* overlaps with a system that controls the way cells in the shoot acquire their unique developmental fates. These two systems were previously thought to be unconnected.



The rate of leaf production by stem cells in the shoot tips is modulated in response to drought. Drought also induces early leaf death and recycles leaf nutrients back into the plant body.

The connection between the two systems was discovered while studying transcription factors, proteins that turn on other genes, that are active in parts of the leaf and in the shoot meristem, where shoot stem cells reside. These factors in turn dictate the inventory of genes expressed in these cells influencing cell identity and behavior. The Barton team discovered that this inventory includes genes related to drought stress far more often than would be expected by chance alone.

The surprise finding that the two systems overlapped led to the prediction that genes with no previously known function, which are present in the overlapping inventory, would act to control leaf production and disposal in response to drought stress. The researchers analyzed one such gene they call *ABIG1*. Importantly, mutations in the *ABIG1* gene result in

In each panel the plant to the right is the mutant (at arrows), which is more resistant to drought conditions. The normal and mutant plants were grown in pairs in the same pot. The pot to the left was well-watered, and the one to the right had water withheld.
Image courtesy Kathryn Barton

> “This work is particularly necessary now, with the more **frequent drought events** we see associated with **climate change.”**

drought tolerance in *Arabidopsis* plants. The mutant plants are resistant to the drought hormone abscisic acid; the leaves do not yellow and die as readily as in normal plants. The mutant plants apparently trigger growth slowdown and leaf death at a higher drought threshold than normal.

This finding shows it is possible to genetically manipulate the drought threshold for breeding drought tolerance. The Barton lab is studying other genes in this overlap category on the hunch that this trove of genetic material can be manipulated to yield drought tolerance. This work is particularly necessary now, with the more frequent drought events we see associated with climate change.

Carnegie’s Kathryn Barton conducts experiments on the laboratory plant *Arabidopsis*, a relative of mustard.
Image courtesy Kathryn Barton

2016-2017 YEAR BOOK

Friends, Honors & Transitions

Carnegie Friends

Lifetime Giving Societies

In 1901, Andrew Carnegie retired from business to begin his career in philanthropy. Among his new enterprises, he considered establishing a national university in Washington, D.C., to compete with the great centers of learning in Europe. But he opted for a more exciting, albeit riskier, endeavor—an independent research organization that would increase basic scientific knowledge. He established the Carnegie Institution in 1902 with a gift of $10 million, ultimately giving a total of $22 million to the institution. Each year Carnegie recognizes those who have contributed to this important legacy. The listings below include those who have generously supported Carnegie Science, including individuals and those who have given from private foundations and donor-advised funds.

The Carnegie Founders Society

Andrew Carnegie's initial $10 million gift represents a special amount. Those who have given Carnegie lifetime contributions of $10 million or more are recognized as members of the Carnegie Founders Society.

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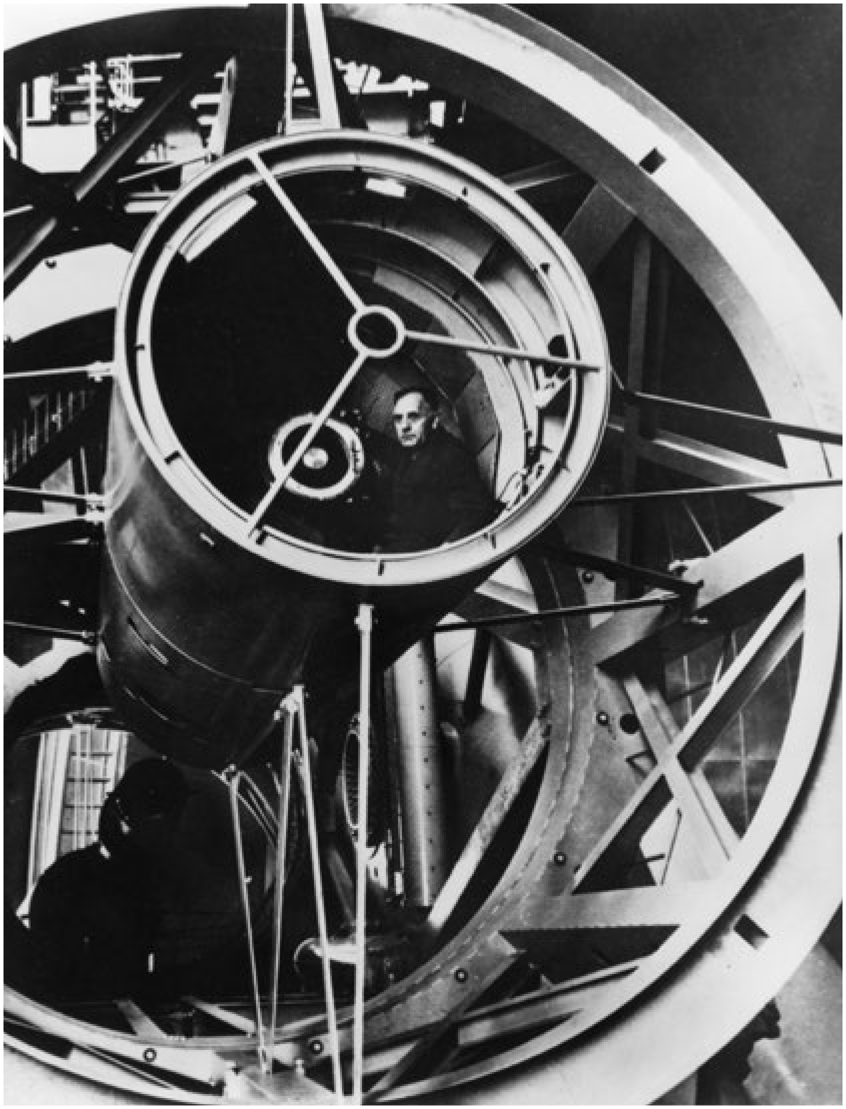

The Edwin Hubble Society

The most famous astronomer of the 20th century, Edwin Hubble, was a Carnegie astronomer. His observations that the universe is vastly larger than what we thought, and that it is expanding, shattered our old concept of cosmology. Science often requires years of work before major discoveries like his can be made. The Edwin Hubble Society honors those whose lifetime contributions have helped the institution to foster such long-term, paradigm-changing research by recognizing contributions between $1,000,000 and $9,999,999.

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Image courtesy Stanford Research Institute

The Vannevar Bush Society

Vannevar Bush, the renowned leader of American scientific research of his time, served as Carnegie's president from 1939 to 1955. Bush believed in the power of private organizations and the conviction that it is good for man to know. The Vannevar Bush Society recognizes those who have made lifetime contributions between $100,000 to $999,999.

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The Second Century Legacy Society

The Carnegie Institution is now in its second century of supporting scientific research and discovery. The Second Century Legacy Society recognizes individuals who have remembered, or intend to remember, the Carnegie Institution in their estate plans and those who support the institution through other forms of planned giving.

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Annual Giving

(Gifts received between July 1, 2016, and June 30, 2017)

The Barbara McClintock Society

An icon of Carnegie science, Barbara McClintock was a Carnegie plant biologist from 1943 until her retirement. She was a giant in the field of maize genetics and received the 1983 Nobel Prize in Physiology/Medicine for her work on patterns of genetic inheritance. She was the first woman to win an unshared Nobel Prize in this category. To sustain researchers like McClintock, annual contributions to the Carnegie Institution are essential. The McClintock Society thus recognizes generous individuals who contribute $10,000 or more in a fiscal year.

$1,000,000 or more

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DONOR SPOTLIGHT

Former Carnegie pre-and postdoctoral fellow Lawrence Taylor

"Good scientists have to be generous and share their knowledge."

Many scientists get the science "bug" at an early age, but not Larry Taylor. Larry's working-class background did not put a premium on education. Larry, who would go on to get a B.S. in chemistry, an M.S. in geology, and a Ph.D. in geochemistry, caught the bug after high school through a series of serendipitous encounters. One landed him at Carnegie's Geophysical Laboratory (GL) in the late 1960s.

Larry Taylor (right) was a student and postdoc at the Geophysical Laboratory (GL) and started supporting Carnegie in 1990. He recently died and his wife Dawn (left) generously set up an endowment in his name to help young GL researchers.

Image courtesy Dawn Taylor

A voracious learner, Larry attended a local community college and took a job in a chemical plant that produced artificial flavors and perfumes. There, he became fascinated with chemistry. The owner, who had a Ph.D., recognized Larry's inquisitiveness and brilliant mind and suggested he attend a university. Despite his lack of funds, Larry attended Indiana University while working.

Larry's passion for geology also came by chance. His roommate was majoring in geology, but was struggling. Larry bet him that it was not that hard and enrolled in the same course. He excelled, became hooked on geology, and eventually earned an M.S.

After a year lecturing in Delaware, he realized that he needed a Ph.D. He received a fellowship at Lehigh University, where he learned about pre-doctoral fellowships at Carnegie.

At Carnegie, Larry was surprised to be surrounded by the luminaries in the field. What particularly astonished him was how generous the scientists were. They shared their knowledge; every question was answered; and the interactions were egalitarian, not hierarchical.

Larry was also introduced to analyzing lunar samples from the Apollo 12 mission. This latest chance encounter changed the course of his career. He consulted on the Apollo Mission and obtained numerous NASA grants, while also working on terrestrial topics granted by NSF.

In 1973, Larry moved to the University of Tennessee, where he remained for the rest of his career. He maintained his Carnegie connections with researchers like Dave Mao and Doug Rumble, who were postdocs when Larry was at the GL.

Larry began donating to Carnegie in 1990 and contributed every year since. This past year, his particularly generous donation elevated him to the Barbara McClintock Society—dedicated to donors who contribute $10,000 or more annually.

Support from former fellows like Larry is essential to the institution. It helps sustain researchers and advances the mission of unfettered scientific investigation. Carnegie is extremely grateful for Larry's steadfast generosity over almost three decades.

The institution was saddened to learn that Larry Taylor died September 18, 2017, just days after his 79th birthday. His wife Dawn generously contributed to this spotlight. Per Larry's wishes she has created an endowment in Larry's memory to support young researchers early in their careers. Dawn remarked, "I know Larry would like it to be used for young investigators, since he got so much help from the Geophysical Lab when he was a student."

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Karyl J. Hurley
Eoin Hurst
Edward Hurwitz
Neil Hurwitz
Robert K. Ihsen
Eugene Imhoff
Bobby R. Inman
Elyas Isaacs
Brian K. Jackson
Madeleine S. Jacobs
Armiger L. Jagoe
Jack C. James
Richard S. James
Eileen M. Janas
James Johnson
Patrick Johnson
Peter Johnson
Richard Johnson
Theodore J. Johnson
Thomas G. Johnson
Blair Jones
Sheila D. Jones
Luis Joya
Nora Jurasits
Jennifer Just
Philip S. Justus
Nan E. Kaeser Davidson
Armin D. Kaiser
Anne C. Kallfisch
Manjula Kasoji
Peter G. Katona
Karen Keeney
John F. Keiser
Sandra A. Keiser*
Brian Kelley
William Kellner
James P. Kelly and
Beverlee Bickmore
Thomas Kelsall
Charles A. Kengla
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Michelle Khine
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Aaron Kofner
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Linda D. Kontnier
David C. Koo
Rita Kopin
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Pamela Koski
Adrienne Kovalsky
G. Gary Kowalczyk
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Jonathan D. Kranz
Jeffrey L. Kretsch
Arthur A. Krieger
Conor Kuzdas
Girard A. Labossiere
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Arlo U. Landolt
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Nicole Lunning
Mica A. Lunt
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Peter B. Lyons
Julia Sever Lytle
Robert Mabin
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Alec Machiels and
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Stephen J. Mackwell
Lauren Macson
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Vanessa Marek
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Richard Mason
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Arnold J. Pryor
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Daniel W. Pugh
Victoria Pursell
Jerome and Dena Puskin
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Gui-Zhong Qi
Velimir Randic
R. P. Ranganayaki
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Shirley Raps
Roberta Rasetti
J. Martin Ratliff and
Carol A. Polanskey
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Hedy Reichard
Thorburn Reid
Minocher C. Reporter
Alberto Reyes
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Randall Speck and
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Samuel D. Stewart
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Cate Strobl
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Richard E. Tenney
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Sarah Thakkar
Alan Thompson
Margaret A. Thompson
Michael Thompson
Peter A. Tinsley and
Marylee H. Hair
Michael Tobias
Daniel Toews
Priestley Toulmin

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John F. Tracy
Dallas Traeger
Martin Trees
Lynette Trygstad
Elizabeth Tuck
James Tucker
Jonathan and Catherine Tuerk
Danny Turkel
Lucia Tyson
Joseph R. Harris and
Cynthia Uleman
Mark Uretsky and Marian Gordon
Samantha J. Valle
Lee Van Duzer
Robert S. Vance
Christopher Vanleuven
W. Karl VanNewkirk
Harold Varmus
Katherine Vasey
Thomas Vaughan
David J. Velinsky and
Susan E. Johntz
Vincent Vella
Clayton Vickland
Katharine Villard
Yan Leonard Vinnik
Daniel and Eloise Vitiello
David Vogel
Steven Voigt
Angela Vollertsen
Willem L. Vos
Mary Voytek
George Vriese
Thomas A. Waddell
Gregory Wagner
Mallory and Diana Walker
Richard J. Walker and
Mary F. Horan
Elizabeth Wallace
Stephen Waller
Douglas J. Wallis
Wayne H. Warren
Ian Watkins
Skyler Weaver
Shirley Webb
Johannes and Julia R. Weertman
Alycia J. Weinberger
Faith Weiner
Jennifer C. Wells
Jane Welna
Philip A. and Barbara A. Wenger
Edward White
William M. White
David G. Whittingham
Julia Wildschutte
James E. Williams
Steven Wilson
David H. Wing
Jeremy Winter
Evelyn M. Witkin
James N. Wolcott
Cecily J. Wolfe
Michael Wolfson
Eric and Sandra Wolman
Mitchell Wong
Carol Wood
Laquita Wood
Margaret D. Woodring
Mary Woolley
Dennis Wykoff
Roy A. Wyscarver
Robert J. Yamartino
Cynthia Yashinski
Pamela D. Yerkes
Henry A. Yost
Richard S. Young and
Bonnie M. Beamer
David Yustein
Victor Zabielski
Robert E. Zadek
Leon Zar
Robert A. Zarzar
Kelly Zehnder
Elizabeth Anne Zimmer
Timothy A. Zimmerlin
Mary Lou and Mark Zoback

* Deceased

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DONOR SPOTLIGHT

Carnegie Trustee David Thompson and Catherine Thompson

“Making a difference with an exceptionally good group of people is appealing.”

David Thompson, Carnegie trustee, and his wife Catherine are Vannevar Bush Society members. They have been generous supporters of the Carnegie Astrometric Planet Search program since 2015. But Dave came to know Carnegie over 20 years before by attending a Capital Science Lecture by Vera Rubin on the rotation rates of galaxies. That research led to the confirmation of dark matter. Dave and Catherine have been attending lectures ever since, and began bringing their daughter Maggie when she was in junior high.

Carnegie trustee David Thompson (left) poses with his daughter Maggie (right) with the expedition flag and photographs documenting the flag’s voyage to and from the International Space Station.
Image courtesy Casey Leffue

Dave grew up in NASA’s Mercury and Gemini era and, like so many, fell in love with space exploration. In college, he worked on the first Mars landing missions and on Space Shuttle projects. Later he worked at Hughes Missile Systems Group. Today he is president and chief executive officer of Orbital ATK, a global aerospace and defense technologies company. Orbital ATK is building the Transiting Exoplanet Survey Satellite (TESS) telescope for NASA, which will be searching for exoplanets. Recently, he hosted a Carnegie staff tour of Orbital ATK, where they saw TESS being built.

Before Orbital ATK, Thompson cofounded and led Orbital Sciences Corporation. Orbital Sciences developed and deployed space and rocket systems. In 2013, it supplied cargo to the International Space Station (ISS). Three years later, Dave surprised Carnegie by having a replicate of the 1900s Department of Terrestrial Magnetism (DTM) expedition flag carried on a resupply mission to the ISS. The flag traveled some 70 million miles before returning to Carnegie. Later Dave presented the framed flag and photographs to the delighted staff.

In 2015, Carnegie hosted an event celebrating the 20th anniversary of exoplanet discovery. By that time, Maggie had developed an intense interest in this field. When she could not attend the event, her father went on her behalf and became hooked on the subject and on Carnegie. He remarked how impressed he was by Carnegie’s contributions to these scientific fields, “especially with its small size and moderate funding.” Dave’s rich experiences in space exploration and enthusiasm for Carnegie made him a natural fit for Carnegie’s board.

Maggie eventually wrote her bachelor’s thesis on a variation of the method developed by Carnegie’s Astrometric Planet Search team. After graduating from Princeton University in 2016, she spent a year conducting research at DTM and is now attending graduate school in astronomy at UC-Santa Cruz.

Carnegie greatly appreciates the Thompsons’ substantial philanthropic support over the years and the particularly collegial engagement they have with Carnegie’s scientific community. This special relationship demonstrates how Carnegie’s public outreach can ignite passion for scientific discovery, and how Carnegie scientists are inspired and empowered by deeply invested donors.

Honors & Transitions

Honors


★ Sandra Faber


★ Marjorie Burger


★ Anat Shahar


★ Bob Hazen

Trustees and Administration

Former Carnegie fellow and current trustee, astronomer **Sandra Faber** was awarded the 2017 Gruber Foundation Cosmology Prize. She was awarded the lifetime achievement award for "her groundbreaking studies of the structure, dynamics, and evolution of galaxies." Her work provided the impetus to study dark matter, the invisible material that makes up most of the mass of the universe, in addition to "the recognition that black holes reside at the heart of most large galaxies."

Marjorie Burger, senior financial analyst in Administration, was awarded the Service to Science Award. She joined Carnegie in 2002 as a financial accountant and was promoted to financial manager/controller in 2007 during a time when Carnegie was expanding and changes were occurring in the regulatory environment because of the financial crisis. She stepped in as the interim director of Administration in 2011 and became senior financial analyst in 2013. However, she was twice asked to return as interim controller based upon urgent needs.

Geophysical Laboratory

Anat Shahar and **Bob Hazen** received the top two awards from the Mineralogical Society of America (MSA) during the Geological Society of America Annual Meeting in September 2016 in Denver, CO. Shahar received the MSA Award which recognizes "outstanding published contributions to the science of mineralogy by relatively young individuals or individuals near the beginning of their professional careers." Hazen received the MSA Roebling Medal. It is "the highest award of the MSA for scientific eminence as represented primarily by scientific publication of outstanding original research in mineralogy."

Global Ecology

Operations manager **Theo van de Sande**, at the Departments of Global Ecology and of Plant Biology, received a Service to Science Award. The depth and breadth of his service to Carnegie is indeed extraordinary. Despite the fact that he has been at Carnegie only four years, he has exhibited outstanding leadership qualities that have been demonstrated time and again. His tireless efforts and genuine concern for the institution as a whole make him truly deserving of this award.

★ Theo van de Sande

Observatories

Over 20 years ago, Carnegie astronomer emeritus **Alan Dressler** chaired the Association of Universities for Research in Astronomy (AURA) Hubble Space Telescope (HST) and Beyond Committee. This committee was awarded the 2017 Carl Sagan Memorial Award presented at the March meeting of the American Astronautical Society. The award stated that "the 1994/1995 study and subsequent published report is widely recognized as the original and most influential activity that led directly to the development of NASA's premier space observatory of the early 21st century, the James Webb Space Telescope."

★ Alan Dressler

Plant Biology

The Howard Hughes Medical Institute (HHMI) and the Simons Foundation awarded **José Dinneny** an HHMI-Simons Faculty Scholar grant. Dinneny is one of 84 scientists chosen out of some 1,400 applicants in a new program that the HHMI, the Simons Foundation, and the Bill & Melinda Gates Foundation have created. The grant will provide $250,000 per year for five years, in addition to overhead expenses, for an award total of $1,500,000.

★ José Dinneny

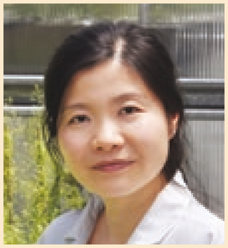
Fifth, Sixth, and Seventh Postdoctoral Innovation and Excellence (PIE) Awards

The Postdoctoral Innovation and Excellence (PIE) Award program was established to recognize exceptional Carnegie postdoctoral scholars who have demonstrated scientific accomplishments, creativity, and community service beyond what is expected. The department directors make nominations for the PIE awards, and the Office of the President chooses the recipient. Under the program, one postdoc is honored every quarter for his or her extraordinary accomplishments. The award recipient is given a cash prize and is the guest of honor at a departmental gathering where all postdocs can enjoy some celebratory pies. The first PIE honor was awarded in 2016.

★ Mary Whelan

Fifth PIE Award: Global Ecology's Mary Whelan

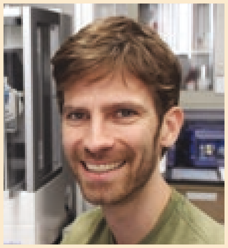
Mary Whelan, in Joe Berry's lab, works on atmospheric trace gas biogeochemistry with an unusual breadth of skills, knowledge, and curiosity. She spends hours of fastidious work on innovative techniques and technology development to measure carbonyl sulfide, which plants consume with carbon dioxide and which can be used to quantify gas flow into plants during photosynthesis. She applies these techniques in the field. Whelan's work has resulted in insights that are novel and were not possible before. Whelan additionally shows an extraordinary knack for collaboration, blending lab fieldwork, and modeling spanning multiple domains that most early career scientists can only partly master. She has also been extremely involved in mentoring, successfully assuring that grant and project collaborations proceed smoothly, and she spearheads many of Carnegie's extracurricular social activities.



★ Jia-Ying Zhu

Sixth PIE Award: Plant Biology's Jia-Ying Zhu

Plant Biology's **Jia-Ying Zhu**, in the Wang lab, was awarded the sixth PIE award for her creativity, productivity, and being a great team player in research "and also an active and caring member of the Carnegie Department of Plant Biology (DPB) community." She has made many innovative contributions to our understanding of the molecular mechanisms that control plant growth according to hormonal, nutritional, and environmental conditions. Additionally, she is always willing to go above and beyond the call of duty to help her colleagues and to mentor students. Zhu is a member of the Carnegie Institution Postdoc Association Council, and she joins in the planning and organization of postdoc social activities, the department retreat, and holiday parties. She also volunteered for *Fascination of Plants Day* at Plant Biology.



★ Zachary Geballe

Seventh PIE Award: Geophysical Laboratory's Zachary Geballe

The Geophysical Laboratory's postdoctoral associate **Zachary Geballe**, in Viktor Struzhkin's lab, was honored with the seventh PIE Award. He develops methods to measure the heat capacities of metals and silicates at high pressures, which applies to developing new materials and studying the deep interiors of planets. Geballe pioneered a technique to measure heat in a diamond anvil cell (DAC) by using a method called the alternating current 3rd harmonic method. He also devised new, sophisticated sample-loading procedures into the DAC with micromanipulator equipment, changing the way the group loads very small samples for experiments. Geballe leads a weekly research seminar and was a founding organizer of postdoc-led poster sessions at the Broad Branch Road campus, which featured the work of nearly all the researchers and sparked new collaborations, approaches, and teamwork.

Transitions

Trustees and Administration

Pamela Matson was elected to join the board at the May meeting. She was appointed the Chester Naramore Dean of the School of Earth, Energy & Environmental Sciences at Stanford University in December 2002. She stepped down from that position December 31, but will continue as the Richard and Rhoda Goldman Professor of Environmental Studies and as a senior fellow of the Woods Institute for the Environment. Matson is world renowned for her work in biogeochemical cycling and biosphere-atmosphere interactions in tropical forests and agricultural systems. Her objective is to identify economically and environmentally sustainable practices.


★ Pamela Matson

David Thompson was elected to the Carnegie board in May. He is president and chief executive officer of Orbital ATK, a multi-billion-dollar global aerospace and defense technologies company that employs some 12,500 employees. Thompson cofounded that company's predecessor, Orbital Sciences Corporation, in 1982 and served as the company's chairman, president, and chief executive officer. Orbital Sciences developed and deployed small- and medium-class space and rocket systems for scientific, defense, and commercial customers. In 2013, it successfully completed a supply run to the International Space Station as part of a NASA contract.


★ David Thompson

Marjorie Burger, senior financial analyst, retired after 15 years with Carnegie. She joined the Administration as a financial accountant in 2002 and was promoted to controller in 2007. In 2011 she stepped in as the interim director of administration and finance, and in 2013 Burger became senior financial analyst. Over the many years she developed a strong bond with the department business managers and the respect of all of her peers within Administration, and among board members.


★ Marjorie Burger

Director of external affairs, **Susanne Garvey** retired after 25 years with Carnegie Science. She was responsible for growing the institution's fundraising activities by developing and managing highly successful fundraising campaigns and gaining major support from foundation grants. Garvey worked closely with scientists from all of the departments, gaining a thorough understanding of their scientific needs to entice donors. She also worked closely with all department directors and many members of the Board of Trustees.


★ Susanne Garvey

Anthony DiGiorgio joined Carnegie as a new associate director of information technology. He came to Carnegie from the Howard Hughes Medical Institute (HHMI) where he was employed since 2000. In his most recent role he managed technology and help-desk functions across the entire institute. His prior roles at HHMI included infrastructure systems architect, senior network engineer, and network administrator. DiGiorgio started his career as a middle school teacher after graduating from the University of Maryland.


★ Anthony DiGiorgio

★ Yixian Zheng

★ Michael Walter

★ Hélène Le Mével

Embryology

After serving as acting director since February 2016, **Yixian Zheng** was appointed director of the department. The Zheng lab studies cell division and the cytoskeleton, the arrangement of rods and fibers and motors that gives shape to cells and allows movement of cell components to specific locations. Zheng has been a staff member at Embryology since 1996. She was a Howard Hughes Medical Institute Investigator from 2000 to 2012. She received a B.S. in Biology from Sichuan University, Sichuan, China, and a Ph.D. in Molecular Genetics at Ohio State University. She was a postdoctoral fellow at the University of California, San Francisco, working with Bruce Alberts and Tim Mitchison and has received numerous honors including a PEW Scholar Award and the Women in Cell Biology Award.

Geophysical Laboratory

Experimental petrologist **Michael Walter**, head of the School of Earth Sciences at the University of Bristol, was selected as the eighth director of the Geophysical Laboratory; he will begin April 1, 2018. He has been at Bristol since 2004. He investigates early Earth's history, shortly after the planet accreted from the gas and dust surrounding our young Sun, when the mantle and the core first separated into layers. He also explores the structure and properties of various compounds under the extreme pressures and temperatures found within the planet, and gains information about the conditions of the mantle from mineral impurities inside diamonds. He received a B.S. in Earth Science from the University of Nebraska, Omaha and a Ph.D. in the same from the University of Texas, Dallas. Walter was a postdoctoral fellow at the Geophysical Laboratory.

Terrestrial Magnetism

Geophysicist **Hélène Le Mével** joined the department as a staff scientist. She received her Ph.D. in 2016 from the University of Wisconsin. Le Mével studies the signals resulting from surface deformations at volcanoes to understand the ongoing magmatic processes in the underlying reservoir. She uses space-based and field-based geodesy to identify, model, and interpret ground deformation. In her Ph.D. research, she used GPS and Interferometric Synthetic Aperture Radar (InSAR) data to study the ongoing unrest at Laguna del Maule volcanic field in Chile. At Carnegie, Le Mével is developing numerical models to investigate the magmatic processes responsible for deformation at large systems rich in silicates, both on timescales over decades and over thousands of years to understand the evolving physical processes in the magma chamber. She plans to apply these models to a variety of volcanic systems and tectonic settings.

This tribute to Carnegie's Vera Rubin is reprinted with permission by Eos Earth & Space Science News

Vera Rubin (1928–2016)

A luminary's luminary, Rubin shed light on the existence of dark matter, blazed a trail for women in science, and inspired and guided subsequent generations of scientists.

Vera Rubin analyzes galaxy data at the Carnegie Institution for Science in 1974. Credit: Carnegie Institution for Science

By Matthew Scott 29 March 2017

The eminent astronomer Vera Cooper Rubin died on 25 December 2016 in Princeton, N.J., at the age of 88. The far-reaching media coverage of her passing chronicled Vera's contributions to astronomy, which earned her countless awards, including the National Medal of Science. She, with longtime collaborator Kent Ford, upended what we thought we knew about the universe.

Their meticulous measurements during the 1960s and 1970s of the orbital speeds of stars in galaxies provided critical evidence of dark matter. Dark matter is invisible. It makes up more than 80% of the mass in the universe. The first inkling of this mysterious material came in 1933 when Swiss astrophysicist Fritz Zwicky of the California Institute of Technology proposed it, and radio observations by scientists, including Morton Roberts and Albert Bosma, during the 1970s advanced the study. But it was not until Rubin and Ford made their observations that most of the astronomical community became convinced of dark matter's existence.

It was not until Rubin and Ford's work that observational evidence for dark matter's existence was found.

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An Extraordinary Career

Vera was also known for much more. With tenacity, grace, and her signature humor, she was prominent as a passionate feminist and a compassionate mentor.

Vera spent most of her career at the Carnegie Institution for Science (familiarly known as Carnegie Science), which supports research in astronomy, Earth science, and life sciences. Vera worked in Washington, D. C., in the Carnegie Department of Terrestrial Magnetism. Carnegie Science has a tradition of supporting exceptional individuals who pursue research agendas with minimal teaching or administrative duties. That independence to concentrate on science has led to many extraordinary discoveries, as Vera's dark matter research exemplifies.

"Soon it was more interesting to watch the stars than to sleep."

Vera certainly was exceptional. In her memoir "An Interesting Voyage," in *Annual Review of Astronomy and Astrophysics*, she reflected that "as a very young child, I was continually puzzled by the curious workings of the world." She recalled wondering why, as she rode in her parents' car, bushes, trees, and houses receded into the distance but the moon stayed "steadily" in the car window.

She remembers that before she was even a teenager, she liked to stare out her bedroom window, fascinated with the night sky. "Soon it was more interesting to watch the stars than to sleep," she remarked. Not long afterward, her father, an engineer, helped her build a telescope. By her own admission, it "was only a moderate success." But, by then, the die was cast.

Ironically, Vera enjoyed almost everything about her Calvin Coolidge High School days in Washington, D. C., except physics. The teacher ignored the few girls in the class, she recalled. When Vera was accepted to Vassar College (Poughkeepsie, N.Y.) with a scholarship, she told that teacher her wonderful news. His response: "You should do OK as long as you stay away from science." Fortunately for all of us, she ignored that sage advice.

Vera Rubin loved telescopes from an early age. In this 1942 photo, the young Vera aligns a homemade telescope that her father helped her build.
Credit: The Rubin Family

Vera graduated from Vassar in 3 years, in 1948, with a bachelor's degree in astronomy and then married Robert Rubin, who was studying chemistry. She obtained her M.A. from Cornell University (Ithaca, N.Y.), where her husband was, and then earned her Ph.D. from Georgetown University (Washington, D. C.) under the tutelage of the famous cosmologist George Gamow. In 1955, Georgetown offered her a faculty position. She had been conducting research, but she also began teaching and continued both for the next 10 years. Rubin famously juggled her academic career to raise four children, a particularly unusual and difficult feat at that time. All four ultimately acquired Ph.D.'s.

She addressed serious issues of gender bias with good humor—but a strong will.

It was not until 1963 that Vera did her first observing, at Kitt Peak National Observatory, near Tucson, Ariz. By then, she had met the famous Carnegie astronomer Allan Sandage, protégé of Edwin Hubble, also of Carnegie. At an astronomy meeting in 1964, Sandage asked Vera if she would like to observe at the Palomar Observatory, which was closed to women at that time, in Southern California. In 1965, she became the first official female to observe there. She noted that the sign on the door to the one bathroom said "Men." On a subsequent trip, she drew a woman with a skirt and put it on that door. She addressed serious issues of gender bias with good humor—but a strong will.

Astronomical observing became important to Vera, and she wanted to quit teaching to focus on it. In January 1965, she walked into Carnegie's Department of Terrestrial Magnetism and asked for a job. After Vera collaborated with Ford on a project, the director agreed to hire her with a two-thirds salary that allowed her to leave early to tend to her children. As they say, the rest is history.

A Dedicated Mentor

In addition to her extraordinary scientific accomplishments, Vera had a huge influence on subsequent generations of researchers. A testimonial page was recently set up in her honor. Many former interns and postdocs contributed. What is particularly striking is how little her vast fame affected her, as these few excerpts from the testimonials illustrate:

- "I learned that I would be spending the summer before my junior year of college interning with Vera Rubin, from a voicemail message left by the director….She [Vera] picked me up from the train station, and I remember being so excited and nervous, wanting to impress her. She took me to her house, where I met her husband….The advice she gave us interns was to do what we loved, regardless of what anyone else thought, and to make trouble for the greater good." —Julia (Haltiwanger) Nicodemus, Assistant Professor, Engineering Studies Program, Lafayette College
- "At one point, she [Vera] just stopped and said, 'Look, you are young. You've got a lot going for you and have already contributed to the field.' She paused for a moment and said, 'Don't let anyone keep you down for silly reasons such as who you are. And don't worry about prizes and fame. The real prize is finding something new out there.'" —Rebecca Oppenheimer, Curator and Professor, Department of Astrophysics, American Museum of Natural History

"The real prize is finding something new out there."

- "I remember starting my first postdoc at DTM [Department of Terrestrial Magnetism] just out of grad school and being in awe that Vera Rubin was just down the hall from me, but [I was] too nervous to actually talk to her. So one day she simply strolled into my office saying, 'Hi, I like to meet all the new postdocs around here. I'm Vera.'" — Hannah Jang-Condell, Assistant Professor, Department of Physics and Astronomy, University of Wyoming

Vera quoted Adlai Stevenson's tribute to Eleanor Roosevelt in her autobiographical article: "It is better to light a candle than to curse the darkness." She commented, "Astronomers, of course, like it dark." To me, her comment is an expression of both her humor and how she coped with the many challenges of her life. Enjoy it when it's dark, especially when bringing enlightenment—which she has done for all of us.

— Matthew Scott (email: in care of tmcdowell@carnegiescience.edu), Carnegie Institution for Science, Washington, D. C.
Scott, M. (2017), Vera Rubin (1928–2016), *Eos, 98*, https://doi.org/10.1029/2017EO070407. Published on 29 March 2017.

2016-2017 YEAR BOOK

Financial Profile

for the year ending June 30, 2017

Reader's Note: *In this section, we present summary unaudited financial information. Each year the Carnegie Institution, through the Audit committee of its Board of Trustees, engages an independent auditor to express an opinion about the financial statements and the financial position of the institution. The complete audited financial statements are made available on the institution's website at www.CarnegieScience.edu.*

The Carnegie Institution for Science completed fiscal year 2017 in sound financial condition after generating a net return of 13.7% on the diversified investments within its endowment; maintaining a disciplined spending policy that balances today's needs with the long-term requirements of the institution and the interests of future scientists; and the continued support of organizations and individuals who recognize the value of basic science.

The primary source of support for the institution's activities continues to be its endowment. This reliance on institutional funding provides an important degree of independence in the research activities of the institution's scientists.

As of June 30, 2017, the endowment was valued at $968 million. Over the period 2001-2017, average annual increases in endowment contributions to the budget were 5.0%. Carnegie closely controls expenses to ensure the continuation of a healthy scientific enterprise.

For several years, under the direction of the Investment committee of the board, Carnegie's endowment has been allocated among a broad spectrum of asset classes including: equities (stocks), absolute return investments, real estate partnerships, private equity, natural resources partnerships, and fixed-income instruments (bonds). The goal of this diversified approach is to generate attractive overall performance and reduce the volatility that would exist in a less diversified portfolio. In 2016 Carnegie hired its first Chief Investment Officer to more proactively steward the endowment's assets.

The Chief Investment Officer and Investment committee regularly examine the asset allocation of the endowment and readjust the allocation, as appropriate. The institution relies upon external managers and partnerships to conduct the investment activities, and it employs a commercial bank to maintain custody. The following chart shows the allocation of the institution's endowment among asset classes as of June 30, 2017.

Asset Class	Target	Actual
Common Stock	35.0%	39.9%
Alternative Assets	57.5%	52.8%
Fixed Income and Cash	7.5%	7.3%

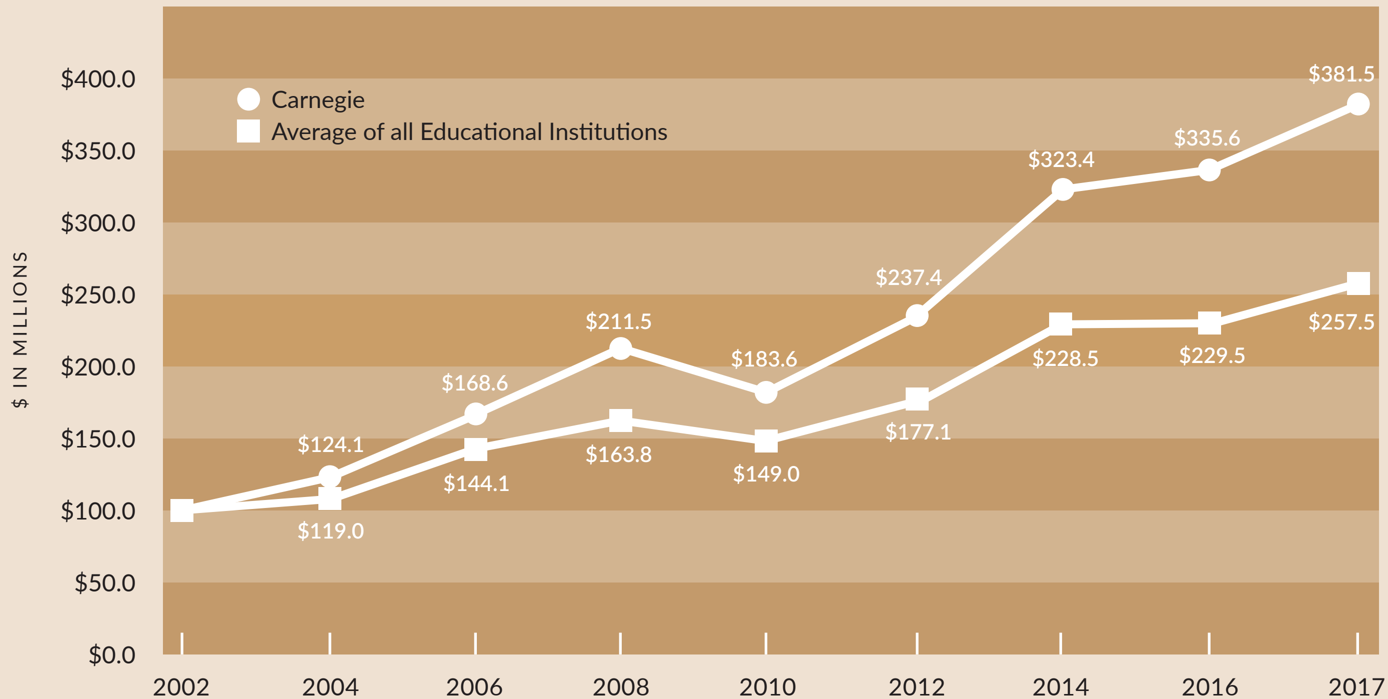
Carnegie's investment goals are to provide high levels of current support to the institution and to maintain the long-term spending power of its endowment. The success of Carnegie's investment strategy is illustrated in the following figure that compares, for a hypothetical investment of $100 million, Carnegie's investment returns with the average returns for all educational institutions for the last 15 years.

Carnegie has pursued a long-term policy of controlling its spending rate, bringing the budgeted rate down in a gradual fashion from 6+ % in 1992 to 5% today. Carnegie employs what is known as a 70/30 hybrid spending rule. That is, the amount available from the endowment in any year is made up of 70% of the previous year's budget, adjusted for inflation, and 30% of the most recently completed year-end endowment value, multiplied by the spending rate of 5% and adjusted for inflation and debt. This method reduces volatility from year-to-year. The second figure depicts actual spending as a percentage of ending market value for the last 15 years.

In fiscal year 2017, Carnegie benefitted from continuing federal support. Carnegie received $17.1 million in new/additional federal grants in 2017. This is a testament to the high quality of Carnegie scientists and their ability to compete successfully for federal funds in this period of fiscal restraint.

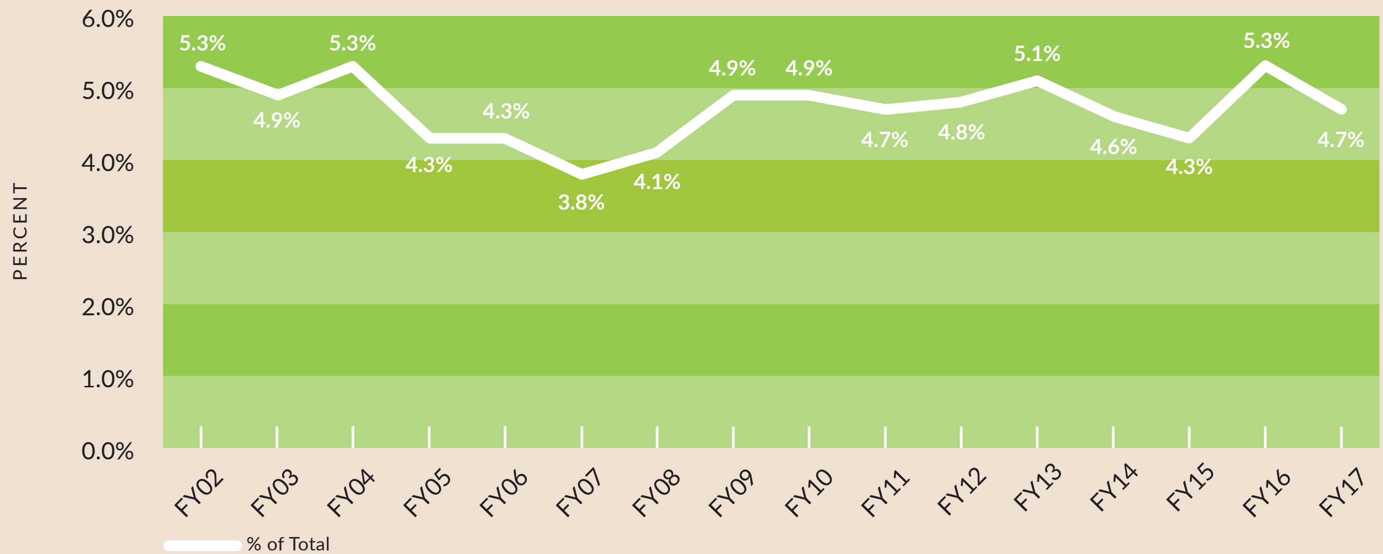
Carnegie also benefits from generous support from foundations and individuals. Funding from foundations has grown from an average of about $3 million/year in the period from 2000 to 2004 to $8.9 million in 2016. While there was a slight decline in 2017, our private grant fundraising continues to be strong. Within Carnegie's endowment, there are several "funds" that provide support either in a general way or targeted to a specific purpose. The largest of these is the Andrew Carnegie Fund, begun with the original gift of $10 million. Mr. Carnegie later made additional gifts totaling another $12 million during his lifetime. This tradition of generous support for Carnegie's scientific mission has continued throughout our history and a list of donors in fiscal year 2017 appears in an earlier section of this year book. In addition, Carnegie receives important private grants for specific research purposes.

Illustration of $100 Million Investment — Carnegie Returns vs. Carnegie Average of all Educational Institutions (2002 - 2017)



Average returns for education institutions are taken from commonfund reports on endowment performance

Endowment Spending Rate as a Percent of Endowment Value



Statement of Financial Position (Unaudited)

June 30, 2017, and 2016

(in thousands)

	2017	2016
Assets		
Cash and cash equivalents	$ 34,466	$ 29,525
Contributions receivable	5,040	4,165
Accounts receivable and other assets (net)	6,306	8,083
Bond proceeds	20,319	25,800
Investments	947,231	877,972
Property and equipment (net)	133,422	133,823
Long-term deferred asset	58,188	56,677
Total assets	$ 1,204,972	$ 1,136,045
Liabilities		
Accounts payable and accrued expenses	17,670	8,205
Deferred revenue	27,685	28,929
Bonds payable	115,045	115,051
Accrued postretirement benefits	25,375	27,675
Total liabilities	185,775	179,860
Net Assets		
Unrestricted	308,316	288,925
Temporarily restricted	655,711	612,104
Permanently restricted	55,170	55,156
Total net assets	1,019,197	956,185
Total liabilities and net assets	$ 1,204,972	$ 1,136,045

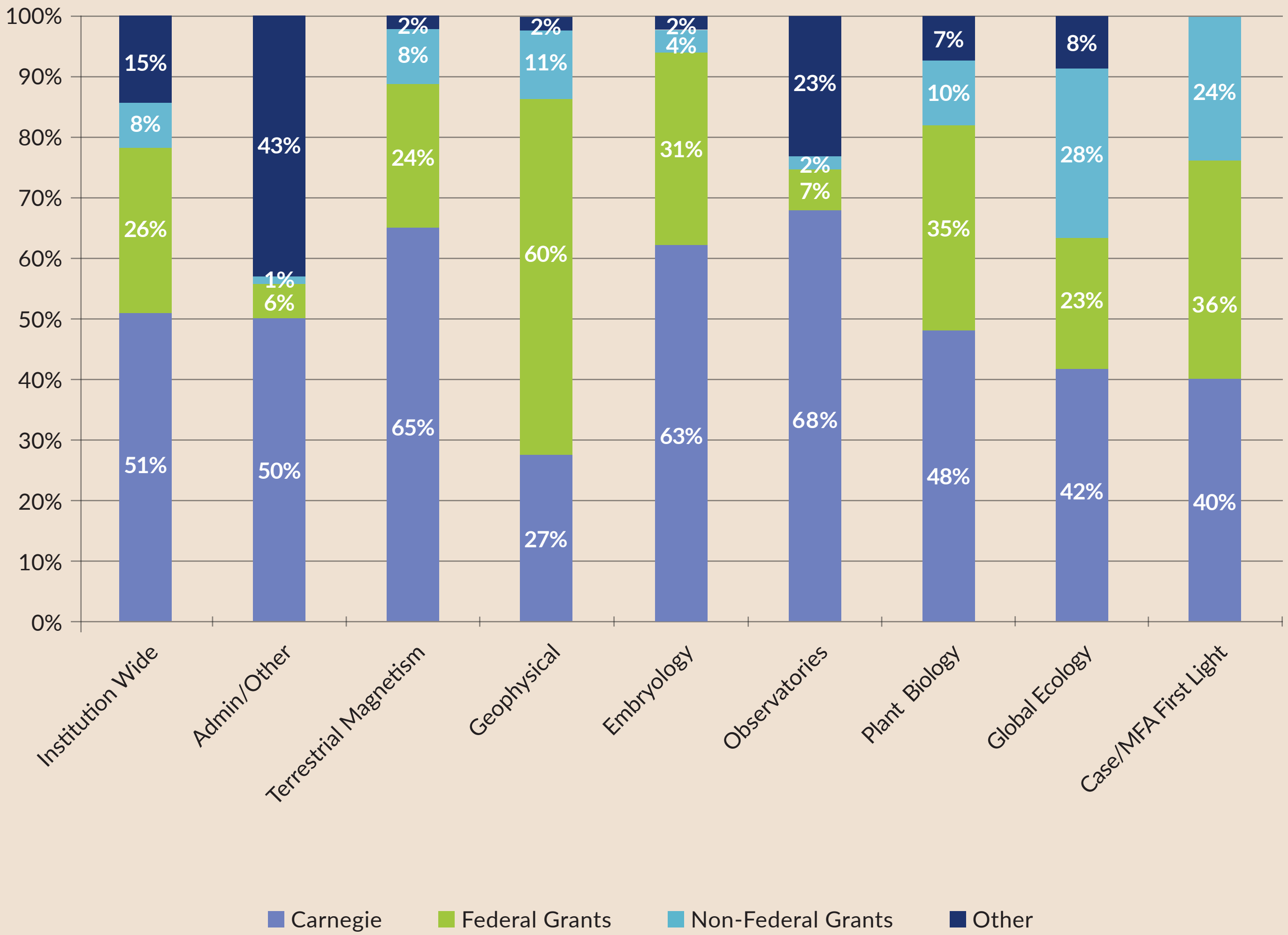
Statement of Activities (Unaudited)

June 30, 2017, and 2016

(in thousands)

	2017	2016
Revenue and Support		
Grants and contracts	$ 30,378	$ 34,549
Contributions, gifts	8,847	7,951
Other Income	1,700	3,999
Net External Revenue	40,925	46,499
Investment income and unrealized gains	120,472	(33,749)
Total Revenue	$ 161,397	$ 12,750
Expenses		
Program and Supporting Services:		
Terrestrial Magnetism	9,722	11,937
Observatories	20,183	17,497
Geophysical Laboratory	20,587	19,651
Embryology	10,912	13,464
Plant Biology	11,330	11,492
Global Ecology	7,279	8,589
Other programs	648	935
Administration and general expenses	21,069	19,099
Total Expenses	$ 101,730	$ 102,664
Change in net assets before pension related changes	$ 59,666	(89,914)
Pension related changes	3,345	(621)
Net assets at the beginning of the period	956,185	1,046,720
Net assets at the end of the period	$ 1,019,196	$ 956,185

Expenses by Funding Type by Department



Small, Lean, and Potent

Some 65 senior Carnegie investigators, with postdoctoral fellows and other colleagues, machinists, business administrators, facilities staff, and more contributed to over 730 papers published in the most prestigious, peer-reviewed scientific journals during the last year. Many discoveries were widely covered by the media and had extensive social media reach.

For a full listing of personnel and publications see https://carnegiescience.edu/yearbooks

1
Year

65
Senior Carnegie Investigators

730
Published Papers

Carnegie Investigators IN THE NEWS

Diamond prospectors are going to “jump on it like crazy.”

STEVEN SHIRLEY, FORBES

“If you can look anywhere on the planet every day, where do you want to put your emphasis in terms of conservation science? Places that can change fast, that’s really the answer.”

GREG ASNER SMITHSONIAN

“Any infringement, especially an entirely unnecessary one, on the free flow of brilliant people ... is shooting ourselves in the foot.”

MATTHEW SCOTT THE WASHINGTON POST

“The increase in photosynthesis has not been large enough to compensate for the burning of fossil fuels.”

JOE BERRY UPI

“We’re missing basically all the crust that was present about 4.4 billion years ago. The question we’re after… is: what happened to it?”

RICK CARLSON PBS

"Vera Rubin, 88, Dies; Opened Doors in Astronomy, and for Women… Her death was announced by the Carnegie Institution…"

VERA RUBIN THE NEW YORK TIMES

"Farmers and agricultural authorities must take account of climate change and the prospect of increased rainfall in designing strategies to mitigate the effects of nutrient pollution. Otherwise, they're going to fail."

ANNA MICHALAK NEW YORK TIMES

"It confirms that human processes are creating new minerals…"

ROBERT HAZEN THE FINANCIAL TIMES

"But the origins-of-life field, like early Earth itself, is a cauldron of roiling theories, each new one challenged and sometimes buried under volcanic flows of criticism."

DOMINIC PAPINEAU POPULAR SCIENCE

"Early this year, a group of astronomers discovered seven Earth-like planets orbiting a single nearby star, TRAPPIST-1. These seven planets might be a good place to search for extraterrestrial life."

ALAN BOSS POPULAR MECHANICS

"We were continuing our survey looking for very distant objects in the outer solar system, which includes looking for Planet X,

SCOTT SHEPPARD POPULAR MECHANICS

Carnegie Investigators

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GEORGE D. CODY, Acting Director
RONALD E. COHEN
YINGWEI FEI
ALEXANDER F. GONCHAROV
ROBERT M. HAZEN
HO-KWANG MAO
BJØRN O. MYSEN
DOUGLAS RUMBLE III
ANAT SHAHAR
ANDREW STEELE
TIMOTHY A. STROBEL
VIKTOR V. STRUZHKIN

THE GEOPHYSICAL LABORATORY »

Matter at Extreme States, Earth/Planetary Science

Front row (left to right): Timothy Strobel, Shaun Hardy, George Cody, Gefei Qian, Nivea Magalhaes, Victor Lugo, Michael Guerette, Jennifer Mays, Simone Runyon, Amanda Lindoo, Michelle Hoon-Starr, Qianqian Wang, Zack Geballe, Craig Schiffries, Venkat Bhadram, Suzy Vitale, Emma Bullock, Adelio Contreras, William (Bill) Key, Michelle Scholtes, Daniel Eldridge, Aline Niyonkuru, Gary Bors, Maceo Bacote, Gabor Szilagyi, Helen Venzon, Jeff Lightfield, Doug Rumble, Andrew Steele, Merri Wolf, Quintin Miller, Dionysis Foustoukos, Pablo Esparza, Yanhao Lin, Tyler Bartholomew, Edgar Steestra. Last row: Seth Wagner, Joseph Lai, Abhisek Basu, Dhiren Pradhan, Ajay Mishra, Matthew Ward, Jing Yang, Li Zhu, Mijanur Rahaman, Gustav Borstad, Hanyu Liu, Chao Liu, Amol Karandikar, Svetlana Shkolyar, Asmaa Boujibar, Michael Ackerson, Teresa Fornaro, Stephen Elardo, Zhixue Du.

Genetics/Developmental Biology

Front row (left to right): Joseph Gall, Alex Bortvin, Yixian Zheng, Christoph Lepper, Zhao Zhang, Allan Spradling, Chen-Ming Fan, Steve Farber. Second row: Kevin Smolenski, Eugenia Dikovsky, Jean-Michael Chanchu, Patricia Cammon, Sara Flamenco, Tyler Harvey, Mahmud Siddiqi, Jen Anderson, Megha Ghildiyal, Han Xiao. Third row: Brandie Dobson, Rejeanne Juste, Casey Hussey, Fred Tan, Myriam Alexander-Kearns, John Urban, Lu Wang, Sungjin Moon, Chenhui Wang, Wanbao Niu, Teng Li. Fourth row: Lynne Hugendubler, Ona Martin, Sonya Bajwa, Valerie Butler, Carmen Tull, Zehra Nizami, Andrew Rock, Amanda Chicoli, Andrew Jacob, Kun Dou, Allison Pinder. Fifth row: Leon Lin, Jui-Ko Chang, Lauren Buda, Marla Tharp, Chiara DeLuca, Mike Sepanski, Penny Pang, Jiabiao Hu, Joseph Tran, Minjie Hu. Sixth row: Glenese Johnson, Ethan Greenblatt, Carol Davenport, Bob Levis, Maggie Shen, Vanessa Quinlivan, Monica Hensley, Jung-Hwa Choi, Ji Cheng, Jeremy Hayes. Last row: Ted Cooper, Devance Reed, Gugu Pang, Melissa Keinath, Sveta Deryusheva, Becca Obniski, Dianne Williams, Aiden Danoff, Xiaobin Zheng. Image courtesy Connie Jewell

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CHEN-MING FAN
STEVEN A. FARBER
JOSEPH G. GALL
MARNIE E. HALPERN
ALLAN C. SPRADLING
YIXIAN ZHENG, Director[1]

Staff Associates

CHRISTOPH LEPPER
ZHAO ZHANG

[1] From February 2017

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FRANÇOIS SCHWEIZER, Staff Member Emeritus
STEPHEN SHECTMAN
JOSHUA SIMON
IAN THOMPSON
RAY WEYMANN, Director Emeritus

[1] Retired December 31, 2016

Research Associates

CHRISTOPHER BURNS, Research Associate
JEFFREY CRANE, Staff Associate
DAN KELSON, Staff Associate
BARRY MADORE, Senior Research Associate
ANTHONY PIRO, Staff Associate

Las Campanas Resident Astronomer

NIDIA MORRELL

[1] Retired December 31, 2016

THE OBSERVATORIES »

Astronomy

Front row (left to right): Scott Rubel, Charlie Hull, Cynthia Hunt. Second row: Jerson Castillo, Greg Ortiz, Gillian Tong, John Mulchaey, Jennifer van Saders, Ben Shappee, Christopher Burns, Thomas Connor, Eduardo Bañados, Marja Seidel, Katherine Alatalo. Third row: Kate Hartman, Sandy Moak, Bryce van Ross, Christina Kreisch, Aracely Cobos, Nicole Relatores, Sal Fu, Milan Roberson, Becky Lynn, Erica Clark, Alan Dressler, Sharon Kelly, Alan Uomoto, Shannon Patel, Christoph Birk, Johanna Teske, Terese Hansen, Alexander Ji, Beverly Fink. Last row: Jorge Estrada, Robert Storts, Stephanie Tonnesen, Taylor Hoyt, Anthony Piro, Fakhri Zahedy, Sung-Ri Sok, Andrew Benson, Carson Adams, Irina Strelnik, Kristin Macklin, Mark Seibert, Paul Collison, Earl Harris, Ken Clardy, Luis Ochoa, George Preston (framed picture) Andrew McWilliam, Vincent Kowal, Michael Rauch, Brian Lorenz, Jeffrey Crane, François Schweizer, Jeffery Rich.

« THE DEPARTMENT OF GLOBAL ECOLOGY

Global Ecology

Front row (left to right): Tuai Williams, Carol McMullen, Jessie Chen, Ma Lopez, Ngoc Ho, Geeta Persad, Joe Berry, Garret Huntress, Theo van de Sande. Second row: Naoia Williams, Maria Canfield, Andrew Davies, Evana Lee, Emily Francis, Dana Chadwick, Yuanyuan Fang, Eva Sinha, Jeff Ho, Anna Michalak, Nina Randazzo, Clare Le Duff, Dario Del Giudice, Ismael Villa. Third row: Freddie Draper, Yelu Zeng, Dave Knapp, Manoela Romano de Orte, Youngryel Ryu, Jen Johnson, Mary Whelan, Scot Miller, Lee Anderegg, Patrick Brown. Last row: Shawna Foo, Greg Asner, Phil Brodrick, Nick Vaughn, Clara Garcia-Sanchez, Tristan Ballard, Anna Posner.

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GREGORY ASNER
JOSEPH A. BERRY, Acting Director[1]
KENNETH CALDEIRA
CHRISTOPHER B. FIELD, Director Emeritus[2]
ANNA MICHALAK

[1] From fall 2016
[2] To fall 2016

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Merle A. Tuve Senior Fellow

JOEL KASTNER, Professor of Imaging Science and Astrophysical Sciences and Technology, Rochester Institute of Technology[3]

THE DEPARTMENT OF TERRESTRIAL MAGNETISM »

Earth/Planetary Science and Astronomy

Front row (left to right): Roberto Molar, Fouad Tera, Steven Golden, Merri Wolf, Kevin Johnson, Tri Astraatmadja, Jianhua Wang, Hélène Le Mével, Rick Carlson, Kei Shimizu, Adriana Kuehnel, Parvin Zahedivash, Pablo Esparza, Wan Kim, Quintin Miller, Alan Boss. Second row: Jesse Reimink, Conel Alexander, Gary Bors, Bill Key, Brad Peters, Scott Sheppard, Jonathan Tucker, Tim Mock, M.A. O'Donnell. Last row: Anaïs Bardyn, My Reibe, Erika Nesvold, Janice Dunlap, Maceo Bacote, Brian Schleigh, Casey Leffue, Diana Roman, Adelio Contreras, Shaun Hardy, Miki Nakajima, Peter van Keken, Mary Horan, Jonathan Gagne, Cian Wilson, Jaehan Bae. Image courtesy Michael J. Colella.

[1] From February 1, 2017
[2] On leave of absence
[3] From January 25, 2017, To March 10, 2017

Plant Science

Front row (Left to right): Jose Sebastian, Winslow Briggs, Jazz Dickinson, Sue Rhee, Evana Lee, Kangmei Zhao, Jiaying Zhu, Ma Lopez, Diana Cai, Zhenzhen Zhang, Shai Saroussi. Second row: Naoia Williams, Carol McMullen, Jessie Chen, Terri Tippets, Veder Garcia, Chan Ho Park, Shouling Xu, Heather Meyer. Third row: Arthur Grossman, Ying Sun, Therese LaRue, Renate Weizbauer, Jiun Yen, Adam Idione, Mackenzie Machado, Diane Chermark. Fourth row: Sophia Clowez, Ngoc Ho, Kathy Barton, José Dinneny, Matt Evans, Lina Duan, Jelmer Lindeboom, Wei Feng, Pascal Schlapfer, Zhi-Yong Wang, Yu-Chun Hsiao, Gisele Passaia Prietsch, Tie Liu. Fifth row: Cesar Cuevas-Velazquez, Fan Lin, Hatem Rouached, Rick Kim, Emanuel Sanz-Luque, Tamara Velosillo, Flavia Bossi, Tuai Williams, Amber Glowacki, Yang Bi, Frej Tulin, Heather Cartwright, Yaniv Dorone, Garret Huntress. Last row: Ankit Srinivas, Theo van de Sande, Lance Cabalona, Marc Horschman, Ismael Villa, Bo Xue, Josep Vilarrasa-Blasi, Haojie Jin, Amanda Lutje.

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- MATTHEW EVANS

Young Investigator

- MARTIN JONIKAS[2]

Senior Investigator

- THEODORE RAAB

[1] To March 31, 2017
[2] To August 31, 2016

Administration

Front row (left to right): Jessica Kerpez, Rosi Vela, Lara Budeit, Marlena Jones, Jackie Williams, Ben Aderson, Jillian Rivera, Brent Bassin, Katia Grigoriants, Yulonda White, Nibret Daba, June Napoco-Soriente, Shanique Washington, Matthew Scott. Second row: Ana Lojanica, Emily Williams, Bianca Abrams, Tim Doyle, Alexis Fleming, Isabella Logossou, Shawn Frazer, Alicia North-Thurston, Loronda Lee, Tina McDowell, Anthony DiGiorgio, Giovonti Vick, Koki Hurley, Jessica Moore, Brian Loretz, Natasha Metzler. Last row: Brady Stoval, Ben Barbin, Tom McDonaugh, Harminder Singh, Michael Stambaugh, Margaret Moerchen, Quinn Zhang, Ann McElwain, Yang Kim, Michael Pimenov, Zulma Amaya, Milan Karol, Tamar Lolua, Kristen Palumbo.

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TIMOTHY DOYLE, Chief Operating Officer
ANN MCELWAIN, Chief Development Officer
MICHAEL STAMBAUGH, Chief Investment Officer
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MARGARET MOERCHEN, Science Deputy to the President

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Carnegie Science

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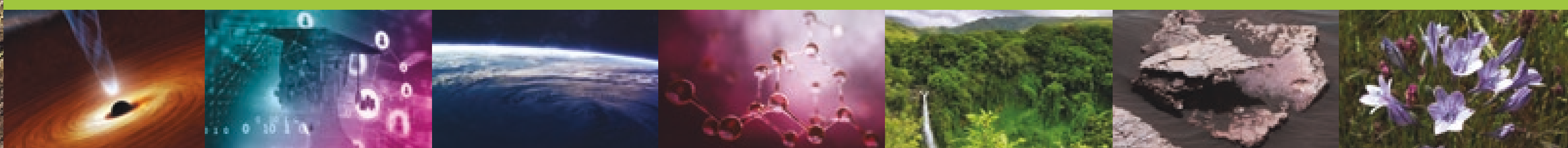

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